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GEOLOGY OF THE GARNET MOUNTAIN QUADRANGLE, GALLATIN COUNTY, MONTANA

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ABSTRACT

The rock sequence in the Garnet Mountain quadrangle, south of Bozeman, in Gallatin County, Montana, includes more than 4,500 feet of sedimentary strata ranging from Flathead Quartzite (Middle Cambrian) to the lower part of the Colorado Group (Cretaceous). Stable to unstable shelf conditions obtained through most of Paleozoic and Mesozoic time. Ordovician, Silurian, Upper Cretaceous, and Paleocene strata are absent, and Triassic rocks are present only in the southwestern corner of the quadrangle. Late Tertiary sedimentary rocks are not known to occur in the map area, though they are abundant to the east and north.

The Paleozoic System is underlain by a complexly deformed Precambrian metamorphic series consisting mainly of various kinds of gneiss, schist, amphibolite, pegmatite, and basic dikes.

Locally, the Paleozoic-Mesozoic sequence is overlain with angular unconformity by a basal Tertiary conglomerate lens, a late early Eocene siltstone, or by probably Eocene volcanic flows and breccias. These younger materials were laid down on a land surface that had local relief as great as 3,000 feet in two miles; they filled the valleys and subdued the relief until they forced the ancient Gallatin River to establish a new course toward the north. Formerly the Gallatin had drained north and east into an ancient Yellowstone River. The present position of the river has been attained by a combination of superposition and antecedence.

Estimated total thickness of the volcanic sequence is about 4,000 feet in the east-central part of the quadrangle and was probably greater prior to later Tertiary and Recent erosion.

Lava flow units of basic andesite composition are intercalated with crudely stratified volcanic breccias of basic andesitic to more acidic composition. These breccias are interpreted to be principally of volcanic (laharic) mudflow origin. Major volcanism may have begun as early as latest early Eocene and ceased well before late Miocene.

Igneous intrusion of several compositional types have been emplaced as stocks, sills, and dikes. Some of the bodies cut at least the lower part of the andesitic volcanic sequence. The intrusions are mainly porphyritic and have characteristics indicating shallow depth of emplacement. Dacite prophyry occurs as stocks and irregular domed intrusives and as dikes; hornblende andesite porphyry and related diorite, principally as sills; and rhyolite as a dike. In chemical composition the diorite closely resembles the basic andesite extrusives and may represent an intrusive equivalent of the latter.

Two major northwest-trending faults dipping steeply northeast separate the quadrangle into three crustal blocks. The Squaw Creek fault extends diagonally across the north half of the map area and may have a dip-slip component of movement in excess of 6,500 feet. The Spanish Peaks fault crosses the southwest corner of the map area and forms the southwest boundary of the prominent range called the Spanish Peaks. Stratigraphic displacement may be as much as 13,500 feet. Two major northeast-trending fault zones, the Deer Creek shear zone and the Moose Creek thrust zone, seem to be closely aligned, and both dip northwest. The Fox Creek trend in the northeast corner of the map area is almost certainly an additional major northeast-trending fault or fault zone now buried beneath volcanic cover.

All major faults are pre-volcanic and probably served as loci for the Tertiary igneous intrusions. Unconformities in and deformation of the Upper Cretaceous, Paleocene, and early Eocene(?) strata of areas south of the quadrangle indicate that compressive deformation may have begun in Late Cretaceous time and continued sporadically until early Eocene time.

Though compressive folding and faulting within the map area had effectively ceased prior to deposition of the Tertiary volcanic sequence, the Gallatin Range may have been differentially warped and tilted southeastward a few degrees by known younger normal faulting along the northern side of the range and along the east side of the Yellowstone River valley.

The Thumper Lode mica mine has been opened in a zoned pegmatite in Precambrian country rock. The Karst asbestos deposit consists of veins of fibrous anthophyllite in serpentinized Precambrian peridotite bodies. Weak mineralization along faults in the southwestern part of the quadrangle deposited sparse chalcopyrite.

I N T R O D U C T I O N

The senior author began geologic mapping in the Garnet Mountain quadrangle during the summer of 1961 and continued work in succeeding summers, completing bedrock mapping in September, 1963. The junior author has been primarily concerned with the igneous rocks and economic mineral deposits of the area. The quadrangle is part of a current broad, long-range mapping project financed by the National Science Foundation. More detailed work on geomorphological and glacial features as well as detail regarding the igneous rocks are being done by the authors and their colleague, John de la Montagne, and will be reported on in detail at later date.

Location and access.--The Garnet Mountain 15-minute quadrangle (111°00' to 111°15' W. and 45°15' to 45°30' N.) lies in Gallatin County with its northeast corner 11 miles south of Bozeman, Montana (fig. 1). The southeastern part of the mapped area straddles the crest of the Gallatin Range; the western part encompasses Gallatin Canyon and extends up onto the flanks of the Spanish Peaks. West Gallatin River and its tributaries drain all the area except the southeast corner, which is drained by Big Creek, a tributary to the Yellowstone River. U. S. Highway 191 follows the West Gallatin, and logging roads provide access to much of the rest of the area; however, the southeast, east-central, and extreme northeast parts of the area are best reached on foot or by pack train.

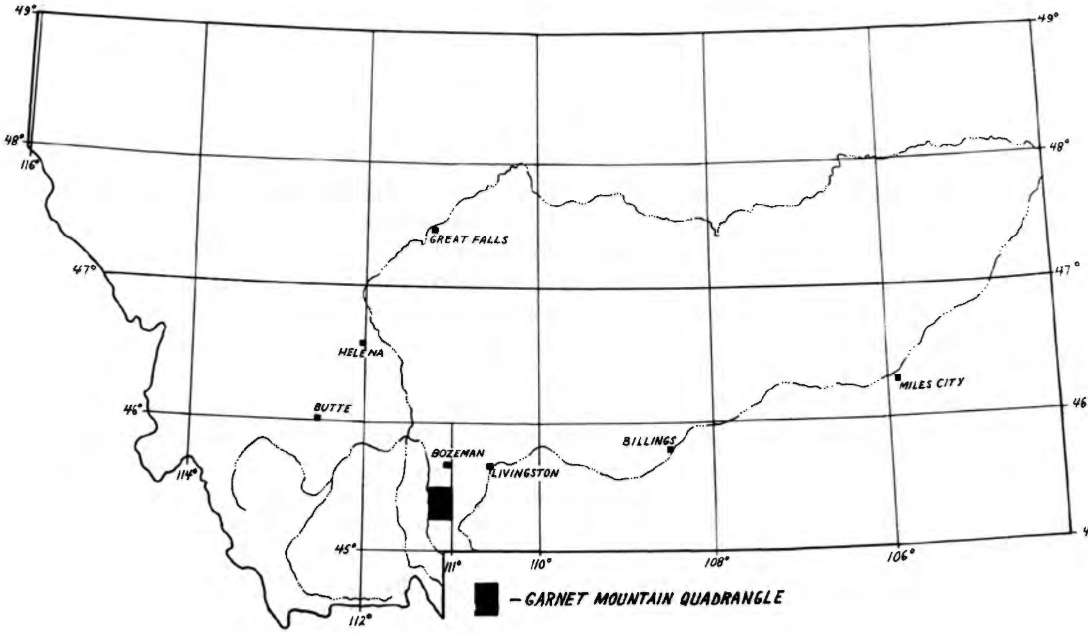


Figure 1.--Index map showing location of Garnet Mountain quadrangle.

Slopes are generally steep and heavily forested. Outcrops are good except near the base of the volcanic sequence where landslides are common. In many places landslides or volcanic rock obscure critical older structural relationships. Elevation ranges from 5,300 feet on the Gallatin River to as much as 10,000 feet on the higher peaks of the Gallatin Range. Local relief exceeds 3,000 feet in many places.

Acknowledgments.--As mentioned above, field mapping and laboratory studies were financed by the National Science Foundation (Project G-24326). Montana State College administers the grant and has provided laboratory research equipment, some travel funds, and library facilities. The Northern Pacific Railway provided some of the aerial photographs used in mapping the northern part of the area. W. W. Boberg, W. A. Van Voast, A. L. Basler, and D. A. Howard served as field assistants. Thanks are due John A. Bowsher of the Galaxy Mining Co. who kindly provided maps and information on the Karst asbestos deposit, and W. T. Barham who gave permission to publish studies on the Thumper Lode mica mine.

Previous work.--The quadrangle was mapped by Peale (1896) as part of the old Three Forks one-degree quadrangle. Mapping by R. W. Swanson (1950) included the southwesternmost part of the area, and numerous geologists have measured stratigraphic sections in the Squaw Creek area. D. B. Hawkins (1956, Unpub. M.S. Thesis, Montana State College) studied intrusive bodies in the vicinity of Storm Castle near the mouth of Squaw Creek. Aside from these investigations, little geologic work has been done in the quadrangle previously.

S T R A T I G R A P H Y

The rock sequence in the Garnet Mountain quadrangle includes more than 4,500 feet of sedimentary strata ranging from Flathead Quartzite (Middle Cambrian) to an unnamed late early Eocene carbonaceous siltstone. Ordovician, Silurian, Upper Cretaceous, and Paleocene rocks are absent in the map area, and Triassic rocks are present only in the southwestern corner of the quadrangle. The Paleozoic System is underlain by a complex Precambrian metamorphic series, and the pre-Cenozoic rocks are overlain unconformably by Tertiary volcanic rocks. Various kinds of Quaternary surficial deposits mask older rocks in many places, but only the larger well-defined masses of these are mapped.

PRECAMBRIAN METAMORPHIC ROCKS

Precambrian metamorphic rocks are extensively exposed to the northern and western parts of the quadrangle (pl. 1) and consist mainly of various kinds of gneiss, schist, amphibolite, pegmatite, and basic dike rocks. No attempt was made to subdivide the Precambrian into map units. Gneiss varieties include red and gray to black and white well-banded granitic types that locally become much more basic by increase in amount of biotite and amphibole. Light-colored finely crystalline granitic gneiss, nearly lacking banding, is also common. Thin schist layers are sparingly present in scattered localities, the most common being a biotite-hornblende type. Other schists include biotite-muscovite, amphibole-chlorite, and muscovite-biotite-feldspar varieties.

Amphibolite occurs as pods, lenses, and continuous distinct layers as much as 50 feet thick. Some are rich in garnet, some are nearly pure black or dark-green amphibole, and others are mixtures of amphibole, plagioclase, and quartz. Gradations from one type to another are common.

Pegmatite and quartz veins are common throughout the metamorphic terrain. Most are fairly small crosscutting or concordant tabular bodies consisting entirely of quartz and feldspar. Some, generally the larger ones, contain biotite, muscovite, or magnetite. One of these pegmatite bodies has been mined for muscovite in the NE$\frac{1}{4}$ sec. 30, T. 4 S., R. 5 E., and is described later. Quartz veins range from pod-shaped or dikelike masses of milky bull quartz to small crosscutting and concordant clear to dark-gray iron-rich veinlets.

Large basic dikes are common in the Precambrian of the Garnet Mountain quadrangle; some exceed 100 feet in thickness. These diabase intrusives generally appear to be unmetamorphosed, though many are extensively sheared. None intrude the Paleozoic strata. The most common dike rock consists of fine- to coarse-grained pyroxene and plagioclase with ophitic texture. Many dikes include appreciable amounts of magnetite. Locally where altered the diabase contains veinlets of serpentine and asbestos. Peridotite bodies also occur. The Karst asbestos mine in sec. 35 and 36, T. 5 S., R. 4 E., is in an intensely altered, highly sheared peridotite lens or lenses and is described in the section on Mineral Deposits.

The metamorphic rocks of the quadrangle are pre-Belt in age, and one radiogenic determination on biotite from granite gneiss in the southwest part of the map area yielded an age of 2,070 million years (Bruno J. Giletti, personal communication, December, 1963). This metamorphic event thus seems to have occurred sometime between events of the area to the west (1,600 m.y., J. P. Wehrenberg, personal communication, 1959) and those on the east end of the Beartooth Mountains (2,750 m.y., Poldervaart and Bentley, 1958, p. 12) and at Jardine on the southwest corner of the Beartooth Mountains (2,420 m.y., Bruno J. Giletti, personal communication, December, 1963). The meaning of the age relationships between the rocks of these various areas is being investigated by Giletti and others.

Cambrian

Cambrian strata of the Garnet Mountain quadrangle are divided into six formations: the Flathead, Wolsey, Meagher, Park, Pilgrim, and Red Lion, which total as much as 1,480 feet in thickness. The map (pl. 1) shows only two Cambrian units, Middle Cambrian (Єm) and Upper Cambrain (Єu). Lithology and distribution of the formations are briefly discussed below.

Flathead Quartzite.--The Flathead Quartzite, of Middle Cambrian age, unconformably overlies Precambrian metamorphic rock in the map area, in most places with marked angular discordance. The formation ranges in thickness from about 125 feet in the northern part of the area to as little as 50 feet in the east-central part. Because of reverse faulting in the southwestern corner of the quadrangle, the Flathead does not crop out there.

Lithologically the formation consists mainly of white, yellow-brown, and red medium- to coarse-grained locally conglomeratic medium- to thick-bedded cross-bedded quartz sandstone. Pebbles are generally less than $\frac{1}{2}$ inch in diameter, but are as large as 1 inch in diameter near Mount Blackmore in the northeast part of the area. The lower part of the formation, 10 to 30 feet thick, generally is arkosic and somewhat more conglomeratic than the rest of the formation. The beds are not notably quartzitic except locally on Garnet Mountain where several sills invade the formation. Glauconite is abundant in some beds, especially in the upper part of the formation where micaceous shale interbeds are also present. In the east-central part of the map area, where the Flathead is only about 50 feet thick, it is also nonresistant, a feature somewhat unusual for the formation in most of western Montana.

Wolsey Shale.--The Wolsey Shale, of Middle Cambrian age, conformably overlies the Flathead Quartzite, and ranges from 140 feet thick at Garnet Mountain to 170 feet thick at Mount Blackmore. Because of poor exposures or faulting, sections were not measured elsewhere in the quadrangle. The Wolsey consists mainly of gray-green and maroon fissile micaceous shale and interbedded gray-green to tan platy cross-bedded very micaceous very fine grained quartz sandstone or siltstone. The platy beds are most common in the upper two-thirds of the formation and are characterized by abundant burrows and trails. A few beds of calcareous sandstone and sandy limestone occur in the upper part of the formation. Where baked by sills, as in the Squaw Creek area, the shale is hard and brittle, very dark gray green, and in places is stained red.

Meagher Limestone.--The Meagher Limestone conformably overlies the Wolsey Shale and conformably underlies the Park Shale. The change from limestone to shale is gradational upward and downward. All three formations are of Middle Cambrian age. Thickness of the Meagher ranges from 449 feet at Garnet Mountain to 471 feet near Mount Blackmore. Elsewhere in the quadrangle partial loss of section or intensive shearing, both related to faulting, preclude accurate measurement of thickness. The formation consists mainly of medium-gray and yellow mottled thin-bedded limestone. The gray part of the rock is dense brittle relatively pure limestone; the yellow part is fine-grained argillaceous to silty limestone in thin discontinuous partings and irregular patches. The lower one-third of the formation contains interbedded yellow and gray-green calcareous shale and a few thin limestone-pebble conglomerate beds. The upper 100 feet of section contains abundant yellow silty partings, as well as a few limestone-pebble conglomerate and fossil-hash beds. Glauconitic limestone is common near the top. Both the lower and upper parts of the formation are nonresistant, whereas the medial part is a ledge-forming unit.

Park Shale.--The Park Shale conformably overlies the Meagher Limestone and ranges in thickness from 175 feet in the southwest to 241 feet in the northwest; it is 217 feet thick in the northeast part of the map area. The formation consists mainly of gray-green and maroon fissile finely micaceous shale but includes a few thin beds of brown very fine grained calcareous quartz sandstone or siltstone. Beds in the upper 10 to 15 feet consist of pale-gray-brown dense thin-bedded limestone and interbedded yellow-brown calcareous shale. The lower 15 to 20 feet of section includes a few thin beds of very glauconitic limestone and of limestone-pebble conglomerate. Exposures generally are very poor. The top of the formation coincides approximately with the Middle Cambrian-Upper Cambrian faunal boundary.

Pilgrim Limestone.--The Pilgrim Limestone, of Late Cambrian age, conformably overlies the Park Shale with a sharp contact. Thickness of the formation ranges from 170 feet in the southwestern part of the map area to about 255 feet in the northern part.

The Pilgrim is divisible into two major units. The lower one consists of a basal gray-brown medium-grained oolitic thick-bedded ledge-forming limestone overlain by interbedded gray and green medium- to coarse-grained medium-bedded fossil-fragmental, in places oolitic, very glauconitic limestone, limestone-pebble conglomerate, some of edgewise type, and green fissile calcareous shale. Beds in the upper 20 to 25 feet of the lower unit consist of yellow-gray to pinkish-gray thin- to medium-bedded dolomite and dolomitized flat-pebble conglomerate, interbedded with thin layers of green to gray-green dolomitic shale.

The upper unit is a massive ledge-forming carbonate that grades from dolomitic limestone in the northeast and east-central parts of the area to dolomite in the northwest and southwest parts. In the northeast, near Mount Blackmore, and on Moose Creek in the east-central part of the map area the upper unit is much like that described in the Bridger Range (McMannis, 1955) and in the Beartooth Mountains (Dorf and Lochman, 1940). It consists of dark-gray and pale-gray-brown mottled medium-grained oolitic medium- to thick-bedded dolomitic limestone. The mottling is a product of partial dolomitization of a pre-existing oolitic limestone (McMannis, 1955; Brown, 1959). Also intercalated are a few beds of limestone-pebble conglomerate. Cross-bedding is obscure. Beds in the upper 10 to 20 feet of the unit consist of medium-gray and yellow mottled dense thin-bedded limestone, identical to the Meagher type. In the northwestern part of the area the upper Pilgrim unit consists of a vaguely mottled distinctly cross-bedded dolomite. The rock is pale gray brown, medium grained, and medium to thick bedded. The original oolitic texture and the earlier partial dolomitization (mottled character) have been almost destroyed in a second, more nearly complete phase of dolomitization. At Dudley Creek, in the southwestern part of the area, about 85 feet of the upper massive unit of the Pilgrim was removed by erosion prior to deposition of overlying Devonian strata, consequently the Pilgrim is much thinner there than in areas to the north and northeast. The remaining massive carbonate at Dudley Creek is a pale-gray-brown medium-grained thick-bedded dolomite showing extremely vague mottling and obscure cross-bedding. This unit has been mapped as the Bighorn Dolomite (Ordovician) by Swanson (1950), but there is no question as to its true stratigraphic designation, because it grades downward into typical lower Pilgrim strata.

<u>Red Lion Formation</u>.--The Red Lion Formation, of Late Cambrian age, is divisible into two members, a lower one--the Dry Creek Shale member--and an unnamed upper carbonate sequence. The Formation is referred to here as Red Lion, rather than Snowy Range, because of a predominance of ribbony carbonate beds. The Red Lion is absent in the southwest and locally in the northwest parts of the map area and is 130 feet thick on Garnet Mountain, 180 feet thick at Moose Creek, and 235 feet thick near Mount Blackmore. The variation is due mainly to depth of pre-Devonian, post-Cambrian erosion.

The Dry Creek Shale member consists of green and gray-green fissile finely micaceous shale with several intercalated platy ledges of yellow-brown very fine grained quartz sandstone or siltstone. Locally, as at Mount Blackmore and in the vicinity of Garnet Mountain, lenses and pods of algal limestone and limestone-pebble conglomerate are present in the upper 5 feet. The member ranges from zero to 35 feet in thickness.

The upper unnamed member of the Red Lion Formation is characterized by a preponderance of pale-gray-brown fine- to coarse-grained thin- to medium-bedded dolomite, containing abundant discontinuous siliceous silty ribbony laminae and partings, and abundant pale- to medium-gray chert nodules and stringers. In some places the upper part contains many large irregular chert masses, and at Mount Blackmore the upper 15 feet of the formation is almost entirely silicified. The silicification and dolomitization of the Red Lion, as well as the second phase of dolomitization of the Pilgrim, are believed to be the result of alteration during exposure prior to Devonian deposition.

The lower part of the upper unnamed member includes a few feet to as much as 35 feet of gray-brown, yellow- and red-stained dense to very coarse grained thin-bedded limestone and fossil-hash beds interbedded with limestone-pebble conglomerate and gray-green fissile shale. These lithologic types are thickest where the overlying ribbony carbonates are thicker, as on Garnet Mountain, at Mount Blackmore, and on Moose Creek. These beds contain many trilobites and brachiopods.

The well-exposed irregular erosional contact between Maywood (Devonian) strata, and the Red Lion and Pilgrim formations near the Squaw Creek Ranger Station has been described previously (McMannis, 1962).

ORDOVICIAN AND SILURIAN

Ordovician and Silurian strata are absent in the Garnet Mountain quadrangle, but the Bighorn Dolomite (Ordovician) is present at Mystic Lake 5 miles northeast of the map area and is reported in the Madison Range to the west and southwest. In the map area the Bighorn was removed by pre-Devonian erosion. Silurian rocks seemingly are absent throughout western Montana.

DEVONIAN

Devonian strata in the Garnet Mountain quadrangle include the Maywood, Jefferson, Three Forks, and Sappington formations. There is still some question as to the precise position of the Devonian-Mississippian boundary (Robinson, 1963, p. 33-38), but in this paper the Sappington is included with the Devonian, both as a map unit and for descriptive purposes. Thickness of the Devonian System ranges from 455 feet at Mount Blackmore to nearly 690 feet near Squaw Creek Ranger Station.

Maywood Formation.--The Maywood Formation occurs as a thin lenticular body at one locality in the quadrangle (NW$\frac{1}{4}$ sec. 28, T. 4 S., R. 4 E.) and is absent elsewhere. In an earlier description (McMannis, 1962), 61 feet of section at the base of the Devonian sequence was assigned to the Maywood Formation, but recent paleontologic and petrographic data (C. A. Sandberg, written communication, July, 1963) indicate that only the lower 34 feet of that sequence should be included in the Maywood. This outcrop is being described in greater detail (Sandberg and McMannis, in preparation). The lens ranges from 0 to 34 feet thick along the 1,000-foot-long northwest-trending outcrop and includes two parts. The lower part consists of yellow-gray to yellow-orange dolomitic, sandy, and conglomeratic siltstone, 0 to 17 feet thick. The basal part of the lower unit is a breccia, probably a regolith derived from underlying Cambrian beds. The contact with the Pilgrim is irregular, narrow channels as much 3 feet deep having been cut into the dolomite. Pebbles of dolomite, chert, and siltstone are common in much of the siltstone unit, and fragmentary remains of armored fish are present. The upper part of the Maywood consists of pale-brownish-gray silty, sandy, and pebbly dolomite in alternating ledge-forming beds and platy nonresistant beds. Thickness of the upper unit ranges from 0 to about 25 feet. Pebbles consist of chert, dolomite, and armored fish fragments. Whole armored fish plates and carbonized wood impressions are found in the lower part of the upper unit. The Maywood is Late Devonian in age.

Jefferson Limestone.--The Jefferson Limestone, of Late Devonian age, lies conformably on the Maywood, or in the latter's absence, disconformably on Upper Cambrian beds. In the southwestern corner of the quadrangle, at Dudley Creek, it rests on a thin, eroded, strongly dolomitized remnant of the ledge-forming upper part of the Pilgrim. The Jefferson ranges in thickness from about 315 feet in the northeastern part of the area, to 450 feet in the northwest; it is about 400 feet thick in the southwest. The upper 50- to 90-foot ledge-forming part of the formation is characterized by medium- to coarse-grained light-colored dolomite, locally containing some fine-grained brown dolomite in the lower part. This unit is separated from lower Jefferson beds by a variably thick solution breccia and shaly dolomite zone. The persistence of these upper units and the variation in lithology at the base of the formation suggest that the difference in total thickness of the Jefferson from place to place may be related to onlap across a surface of appreciable relief (150 to 250 feet).

In general the Jefferson consists of medium-bedded to massive gray and brown dolomite, dolomitic limestone, and limestone, interbedded with gray-green to greenish-yellow argillaceous dolomite or limestone, and solution-breccia zones. Many of the beds have a strong petroliferous odor. Corals and poorly preserved brachiopods occur sparingly but Amphipora and Stromatopora (both phylum Coelenterata) are fairly common. The lower part of the formation tends to be more dolomitic, but this is not everywhere so, for some Jefferson sections in adjacent areas are almost entirely dolomitic.

About a mile north of the northeast corner of the quadrangle, fossils collected from beds about 75 feet below the top of the Jefferson (McMannis, 1962, p. 8) indicate that the beds may be upper Chemung equivalents, an age considerably younger than that assigned previously to the upper Jefferson (Cooper and others, 1942).

Three Forks Shale.--The Three Forks Shale, of Late Devonian age, lies conformably on the Jefferson with sharp contact. In the map area and in adjacent areas, the Three Forks can be subdivided into two lithologic units, neither of which contain much shale (McMannis, 1962, p. 5). The lower one, informally called the Potlatch member, consists of red, yellow, and greenish-orange argillaceous carbonate breccia, a dolomitic shale at the base, and a massive ledge-forming dolomite or limestone at the top.

The thickness of this unit ranges from 90 feet in most of the area to about 135 feet at Dudley Creek. At Timber butte on Squaw Creek the Potlatch member is only 50 feet thick, but the section lies on the flank of a tight fold, close to the major Squaw Creek fault, and may be tectonically thinned.

The upper unit, informally called the carbonate member, consists of medium-gray yellow-weathering dense thin-bedded dolomite or dolomitic limestone and minor gray-green shale partings and flakes. In the western part of the quadrangle the uppermost 5 to 6 feet of this unit is medium-gray massive very dense limestone; however, this limestone is absent in the eastern part of the area. Thickness of the carbonate member ranges from about 25 feet on Moose Creek and Mount Blackmore to about 60 feet at Dudley Creek and Squaw Creek. Absence of dense limestone at the top of the Three Forks, general thinning of the carbonate member eastward, and the silty, sandy, nodular character of the overlying basal beds of the Sappington as well as faunal evidence suggest that there may be a slight disconformity between the Three Forks and Sappington formations.

Sappington Formation.--The Sappington Formation or Sandstone, as the names are used respectively by McMannis (1962, p. 10) and Holland (1952, p. 1706-1709), generally includes a basal black shale and overlying calcareous silty and sandy beds. This usage excludes a black silty shale at the base of the next younger Lodgepole Limestone. In the Garnet Mountain quadrangle the Sappington consists of 23 to 60 feet of gray-brown and yellow-brown calcareous siltstone, mudstone, sandy limestone, and sandstone. Carbonaceous shaly siltstone is present in the lower part of the formation at the Moose Creek section, and the lower part is a very sandy limestone at the Storm Castle section near the mouth of Squaw Creek. The basal beds in both of these sections are very fossiliferous, and those at Moose Creek include the typical ferruginous-calcareous fossil-bearing nodules reported in other Montana sections by Gutschick (1962). Where exposed, sandstone at the top of the Sappington Formation seems to be leached near the contact with the overlying black silty shale.

The formation is included with the Devonian here, both for mapping and descriptive purposes, although there still is some discussion as to where the Devonian-Mississippian faunal boundary lies in the section (McMannis, 1962; Robinson, 1963; Gutschick and others, 1962). From the data at hand, Gutschick and others (1962) conclude that the boundary lies midway up in the Sappington, a conclusion with which we have no quarrel.

MISSISSIPPIAN

Definitely Mississippian strata of the Garnet Mountain quadrangle are included in the Madison Group and are mapped as the Lodgepole and Mission Canyon Limestones. Thickness of the group averages about 1,300 feet in the map area.

Lodgepole Limestone.--The Lodgepole Limestone, of Early Mississippian age, is the most prominent ledge- and ridge-forming sedimentary rock unit in the map area. Thickness ranges from 575 feet to about 610 feet, and the thicker sections occur in the east-central and northeastern parts of the quadrangle.

The Lodgepole consists mainly of thin- to medium-bedded limestone and interbedded argillaceous limestone or calcareous shale. At the base of the formation there is a 3- to 5-foot black silty shale and carbonaceous siltstone or very fine grained sandstone. This unit is present in all stratigraphic sections in the quadrangle except those in the southwest corner near Dudley Creek and consists of a lower 2- to 3-foot silty shale overlain by $1\frac{1}{2}$ to 2 feet of carbonaceous siltstone or very fine grained sandstone that weathers yellow brown to gray brown. The base of the unit rests on leached Sappington sandstone and the top is perfectly concordant with the overlying crinoidal limestone. Persistence of the two-part character of this unit throughout most of the map area and far beyond suggests a remarkably uniform restricted environment over a broad area just prior to influx of well-aerated Lodgepole sea water.

The dominant lithology in the lower 225 to 235 feet of the Lodgepole is medium- or dark-gray dense thin-bedded moderately fossiliferous limestone, and several zones contain abundant chert nodules. A few beds contain abundant crinoid fragments, and there are a few platy argillaceous limestone beds. Prominent cliffs are formed by these lower beds. Rocks in the middle 200 to 225 feet of the formation consist of alternating fossil-fragmental limestone and argillaceous limestone or calcareous shale. The fragmental limestone is fine to very coarse grained gray brown to gray and thin bedded and contains abundant entire fossils and fossil fragments. The argillaceous beds are fine grained yellow gray to yellow brown and very thin bedded and commonly are also fossiliferous. Beds in the upper 140 to 160 feet of the Lodgepole are similar to those of the middle unit but are generally thicker bedded, contain less argillaceous material, and include some 2- to 4-foot coarse crinoid-fragmental limestone beds. The uppermost part of this unit is mainly fine-grained dolomitic limestone and yellow-brown fine-grained argillaceous platy limestone.

Mission Canyon Limestone.--The Mission Canyon Limestone, of late Early and early Late Mississippian age, forms prominent outcrops adjacent to Squaw Creek, north of Mount Blackmore, on Moose Creek, and in the southwest corner of the quadrangle. The formation averages about 675 feet in thickness. Where it recently has been exhumed from beneath the volcanic cover, it is extensively silicified, forming massive chert ledges.

The Mission Canyon consists of pale-gray to pale-gray-brown light-gray-weathering medium- to thick-bedded and massive fine-grained to coarse-grained dolomite, dolomitic limestone, and limestone. Chert nodules and stringers are abundant. Some beds are obviously dolomitized fossil-fragmental limestone; some are oolitic and cross-bedded. Irregular masses of solution breccia are common in the upper 100 feet of the formation. Many of the massive beds are cliff forming

In nearby areas the upper part of the Mission Canyon is Meramecian (early Late Mississippian) in age (Andrichuk, 1955, p. 2179; Roberts, 1961, p. B 294; Sando and Dutro, 1960, p. 117, 123). No attempt was made to determine the age of the upper Mission Canyon in the map area, but probably its age is similar to that in adjacent areas.

MISSISSIPPIAN AND PENNSYLVANIAN

Strata overlying the Mission Canyon and underlying the Phosphoria Formation (Permian) are described under this heading, and these plus the Phosphoria Formation are lumped together as a map unit (Caqp). The beds of this sequence are variously subdivided in neighboring parts of Montana and Wyoming according to the criteria used for picking the contact between the Amsden and Quadrant formations.

Amsden Formation.--The Amsden Formation, of latest Mississippian and Early Pennsylvanian age, is one of the most variable formations in the map area. It ranges from 0 to about 225 feet in thickness. As interpreted here, the formation is absent in the Squaw Creek area.

The Amsden consists of yellow-gray thin- to thick-bedded medium- to coarse-grained dolarenite, pale gray-white dense thin- to medium-bedded dolomite, gray-brown fine-grained medium-bedded to massive fossiliferous limestone, purplish-red dense dolomitic mudstone and argillaceous dolomite, and minor green and red flaky dolomitic shale. Proportions of these several rock types vary markedly from section to section; however, red strata are present wherever the formation is present. The top of the highest red stratum in the Mission Canyon-Quadrant sequence was taken as the top of the Amsden, a criterion more reliable than picking the Amsden-Quadrant contact on the basis of relative amounts of sandstone and carbonate as has been done in other areas.

Poorly preserved fossils are fairly common in the limestone beds, but no collections were made, and the age assignment made above is based on data from nearby areas (McMannis, 1955; Robinson, 1963).

Quadrant Formation.--The Quadrant Formation, of Pennsylvania age, generally ranges from 135 feet to 250 feet in thickness. It is thickest in the northeast part of the quadrangle, thinnest in the Squaw Creek area, and is about 205 feet thick in the southwest corner of the map area.

The formation consists of pale-gray-white or pale-cream-colored (stained red to yellow brown) medium- to thick-bedded cross-bedded fine- to medium-grained quartz sandstone that is locally quartzitic but in most places is only moderately cemented. Pale-yellow-brown medium-bedded medium-grained sandy dolomite and pale-gray dense thin- to medium-bedded dolomite are intercalated with quartz sandstone in the lower part of the formation.

No fossils were observed in the Quadrant, and the age assignment is based on conclusions reached by others in regional studies.

PERMIAN

Strata of the Phosphoria Formation are lumped on Plate 1 with the Amsden and Quadrant in a single map unit (Caqp); the Permian part is described separtely here.

Phosphoria Formation.--The Phosphoria Formation, of Permian age, occurs throughout the map area. Measured thickness is 119 feet in the southwestern corner of the quadrangle and 105 feet on Squaw Creek and it may be less in the northeastern part of the map area where poor exposures prevent accurate measurement. About 12 miles to the north-northeast, at Rocky Canyon, the formation is only about 25 feet thick, and 6 miles farther north, on the south end of the Bridger Range, it is absent (McMannis, 1955). The formation is also absent less than 3 miles north of the north-central part of the map area, in the lower canyon of South Cottonwood Creek.

The formation consists of a lower unit 39 to 43 feet thick and an upper unit 66 to 76 feet thick. In the southwest part of the area the lower unit from bottom to top includes gray to yellow-brown nodular chert, gray-brown medium-grained thick-bedded quartzite, and yellow-brown silicified siltstone interbedded with chert. The quartzite includes a thin conglomeratic zone in its mid part, made up of pebbles of limestone, chert, and quartzite as much as 2 inches long. To the north, on Squaw Creek, the lower unit contains less chert and a greater amount of quartzite. The quartzite of both localities includes abundant fragments of chert and phosphate rock.

The upper unit consists mainly of gray-brown thin- to thick-bedded fine- to medium-grained quartzite; and in its upper part, intercalated very irregularly bedded nodular chert and quartzite. Most of the quartzite beds contain abundant distinctive large tubular burrows.

The Phosphoria strata of the Garnet Mountain quadrangle seem to be equivalent to Unit E of the formation as described by Cressman (1955). None of the beds exposed in the quadrangle contain enough phosphate to be of economic significance.

TRIASSIC

Triassic strata are not exposed in the Garnet Mountain quadrangle except in the southwesternmost part. They are absent along Squaw Creek and in areas farther north where Jurassic beds rest directly on the Phosphoria or on the Quadrant. Triassic rocks may be present in the Moose Creek-Swan Creek area; if so, they are covered by Tertiary volcanic rocks.

Dinwoody Formation.--The Dinwoody Formation, of Early Triassic age, is about 265 feet thick in the southwestern part of the map area but is not exposed elsewhere in the quadrangle. Exposures are very poor and most of the formation is covered; thickness is estimated on the basis of width of outcrop and float.

The lower 15 feet consists of gray-brown coarse-grained thick-bedded sandy limestone containing linguloid brachiopods, and locally contains brown fine-grained sandstone. Sporadic outcrops and talus on the rest of the formation consist of platy calcareous siltstone or silty limestone, some of which is fossiliferous. The contact with the underlying Phosphoria Formation seems to be conformable.

JURASSIC

Jurassic strata in the Garnet Mountain quadrangle include the marine Ellis Group, comprising the Sawtooth, Rierdon, and Swift formations, and the nonmarine Morrison Formation. The total thickness of the Jurassic ranges from 600 feet to nearly 700 feet. These rocks are shown as a single undifferentiated map unit (Ju) on Plate 1.

Sawtooth Formation.--The basal unit of the Ellis Group, the Sawtooth Formation of Middle Jurassic age, rests disconformably on the Dinwoody Formation in the southwest corner of the map area, and elsewhere in the quadrangle it rests disconformably on the Phosphoria. Thickness of the Sawtooth is 120 feet in the southwestern part of the map area, and increases northward to about 160 feet on Squaw Creek, and northeastward to 185 feet in the northeast corner of the quadrangle.

The Sawtooth consists mainly of dark-gray light-gray-weathering blocky thin-bedded fine-grained limestone, shaly limestone, and calcareous shale. Many beds are abundantly fossiliferous. The lower 50 to 60 feet of the formation also includes yellow-brown siltstone breccia, gray-green gypsiferous silty shale, and yellow-brown very fine grained to pebbly sandstone. In the southwestern part of the area the upper 45 feet of the Sawtooth consists of yellow-brown calcareous sandstone, sandy limestone, and silty or sandy shale. In the northeast part of the area the upper 60 to 70 feet of the formation consists of yellow-brown and reddish siltstone and mudstone.

Rierdon Formation.--The Rierdon Formation, middle unit of the Ellis Group and of Middle and Late Jurassic age, rests conformably on the Sawtooth Formation. It ranges in thickness from 28 feet to 63 feet in the quadrangle.

In most of the map area the formation consists of ledge-forming thick beds of gray-brown gray-weathering densely oolitic limestone, but in the northeast corner of the area, where the formation is thicker, strata in the upper 40 feet consist of yellow-brown fossiliferous calcareous shale in which are intercalated a few thin limestone beds. Absence of the latter shale in the rest of the area is attributed to pre-Swift erosion.

Swift Formation.--The Swift Formation, of Late Jurassic age, rests disconformably on the Rierdon (Imlay and others, 1948; Imlay, 1956). Absence of the upper Rierdon shale, very persistent in areas just to the north and east, suggests removal by pre-Swift erosion and is supporting evidence of unconformity at the base of the Swift. The Swift ranges in thickness from 25 feet on Squaw Creek to 115 feet in the southwest corner of the map area.

The formation consists of yellow-brown to greenish-yellow-gray thin- to medium-bedded cross-bedded ripple-marked very fine to medium-grained sandstone, in places pebbly. Sandstone beds are very calcareous, generally glauconitic, and in places grade into very sandy limestone. Fossils are common. Pebbles in the conglomeratic zones consist mainly of white, green, and dark-gray chert.

Morrison Formation.--The Morrison Formation, of Late Jurassic age, lies conformably upon the Swift Formation and thickens from 275 feet in the northeastern part of the map area to 450 feet on Squaw Creek, and thence thins to 335 feet in the southwest corner of the area.

The formation consists of variegated red, green, and gray mudstone, shale, and siltstone, and includes a few discontinuous yellow- to orange-brown thin- to thick-bedded very fine grained sandstone or siltstone beds. Some exposures contain thin zones of nodular silty limestone, and some include yellow-brown massive cross-bedded coarse-grained sandstone. The upper one-quarter to one-third of the formation is characterized by somber colors, whereas the lower part is commonly dominated by red, green, and yellow brown.

CRETACEOUS

Cretaceous strata (Kootenai Formation and basal part of Colorado Group) occur only on Squaw Creek and in the southwest corner of the quadrangle. The thick younger Cretaceous sections reported in nearby areas (McMannis, 1955; W. B. Hall, 1961, Unpub. Ph.D. Thesis, Univ. of Wyoming) are absent in the Garnet Mountain quadrangle, in part owing to recent erosion and erosion prior to deposition of the Tertiary volcanic rocks, but possibly also in part owing to nondeposition. Younger Cretaceous strata adjoin the exposures of Kootenai and Colorado at the southwest corner of the map area.

Kootenai Formation.--The Kootenai Formation, of Early Cretaceous age, rests unconformably on the Morrison Formation, and ranges in thickness from 360 feet on Squaw Creek to 412 feet in the southwest corner of the quadrangle.

The formation includes three distinctive units. The lowest of these is the basal Kootenai conglomeratic sandstone, which is gray, thick bedded, cross-bedded, and commonly coarse grained and conglomeratic. In its upper part the sandstone is fine grained. The basal sandstone is 75 to 85 feet thick and supports fairly prominent ridges, ledges, and cliffs. Pebbles consist of light- to dark-gray chert, quartzite, and limestone, in that order of abundance. The sandstone is also characterized by abundant chert grains and secondary overgrowths of quartz.

Overlying the basal sandstone are variegated red and gray shale and mudstone, fine-grained yellow-brown sandstone or siltstone, and yellow-gray, gray, and purple fresh-water limestone totaling 250 to 260 feet thick. Red mudstone is the most abundant rock type. The limestone occurs in two thin zones about 50 feet and 100 feet above the basal Kootenai sandstone, and both zones thin northward.

The upper 35 to 50 feet of the Kootenai includes a distinctive gastropod- and ostracod-bearing fresh-water limestone overlain by various thicknesses of variegated red, yellow-brown, and gray mudstone. The "gastropod limestone" is a persistent stratigraphic marker in the upper part of the Kootenai in much of southwestern Montana.

Colorado Group.--Post-Kootenai Cretaceous strata of the Garnet Mountain quadrangle are included in the undifferentiated Colorado Group. Only the lower few hundred feet of the group is exposed, but younger Cretaceous beds are present in quadrangles adjacent to the southwest corner of the map area.

The Colorado beds of the map area include basal yellow-brown thin- to medium-bedded fine-grained clean quartz sandstone or quartzite interbedded with gray siltstone and overlain by dark-gray fissile shale interbedded with gray to gray-brown thin-bedded siltstone.

Recent erosion and erosion prior to deposition of the Tertiary volcanic sequence apparently removed these and some of the younger Cretaceous beds over much of the map area; however, much of the Upper Cretaceous sedimentary column may be absent because of nondeposition.

CENOZOIC

Cenozoic sedimentary map units of the Garnet Mountain quadrangle include, from older to younger, a basal Tertiary conglomerate, a late early Eocene siltstone, and Quaternary alluvial and landslide materials. No attempt is made here to further classify and subdivide the Quaternary deposits, though it is known that there are several levels of river gravels as well as at least two separate glacial sequences. These younger deposits are being studied by our colleague, John de la Montagne. The conglomerate and the siltstone are described here.

Basal Tertiary conglomerate.--A thin, very poorly exposed conglomerate overlies Paleozoic and Precambrian rocks in the area southwest of Rat Lake (sec. 10, 11, and 12, T. 5 S., R. 4 E.). The conglomerate appears as the basal unit of the Tertiary sedimentary and volcanic sequence, and in the Rat Lake area underlies a late early Eocene carbonaceous siltstone. Contacts with overlying and underlying materials are not exposed, and stratigraphic position of the conglomerate is indicated by areal distribution and dip relationships.

The conglomerate consists of cobbles and boulders of Precambrian gneiss, amphibolite, and vein quartz, some of Paleozoic carbonate rock, and a few of intermediate to basic volcanic rock. The matrix is coarse-grained pebbly sand consisting of minerals common to the cobble and boulder types. The conglomerate is poorly indurated and is well exposed only in road cuts. Many of the cobbles and boulders are much decomposed and disintegrate easily. The basal part of the unit on the ridge crest in the SW$\frac{1}{4}$ sec. 11, T. 5 S., R. 4 E., is a silicified sedimentary breccia.

Similar conglomerates are known to occur at the base of the volcanic sequence in the northern part of Gallatin Range at Grotto Falls (NE$\frac{1}{4}$ sec. 3, T. 5 S., R. 6 E.), Palisade Falls (center S$\frac{1}{2}$ sec. 24, T. 4 S., R. 6 E.), and Chimney Rock (NW$\frac{1}{4}$ sec. 31, T. 3 S., R. 8 E.). A similar conglomerate also occurs at the base of the Cenozoic sequence in Yellowstone Park and adjacent areas where it is thought to be of early Eocene age (Pierce, 1957; Brown, 1961). All such conglomerates are probably isolated lenticular stream deposits formed in valleys of the pre-volcanic landslide.

Late early Eocene siltstone.--At several places in the Squaw Creek area a thin discontinuous poorly exposed carbonaceous siltstone overlies Precambrian metamorphic and Paleozoic sedimentary rocks, or lies conformably(?) on the basal Tertiary conglomerate. The siltstone is gray to gray brown, thin bedded to fissile, micaceous, and sandy in places, and contains abundant carbonaceous plant fragments. Spore and pollen analyses tentatively indicate a Wasatchian (late early Eocene) age for this siltstone (written communication, A. E. Roberts, 1962).

The siltstone is exposed at several places along the Rat Lake logging road in sec. 1, 11, and 12, T. 5 S., R. 4 E. The best exposures are in the SW$\frac{1}{4}$ sec. 33, T. 4 S., R. 5 E., on the undercut southeast bank of Smith Creek.

GEOLOGY OF IGNEOUS ROCKS

TERTIARY VOLCANIC ROCKS

Volcanic rocks in the Garnet Mountain quadrangle unconformably overlie the Precambrian metamorphic rocks and the Paleozoic-Mesozoic sequence and cap most of the higher ridges including the backbone of the Gallatin Range. Observed thickness of the volcanic pile exceeds 2,400 feet in the upper Squaw Creek area and reaches 3,000 feet in parts of the adjacent Fridley Peak quadrangle. Presumed total thickness from ridge tops to the base of the pile, as determined from contours of the pre-volcanic topographic surface (fig. 2), exceeds 4,000 feet in the upper Squaw Creek drainage. Additional thicknesses of volcanic materials were evidently eroded from above the present ridge crests.

The sequence is crudely layered and dips predominantly eastward and southeastward 5 to 10°, extending across the entire Gallatin Range to the Yellowstone River valley in the Fridley Peak and Emigrant quadrangles. Peale (1896) briefly described the volcanic rocks of the Garnet Mountain quadrangle, noting the presence of andesitic breccias, agglomerates, and flows. Little work has been done on the volcanic rocks since that time.

Two lithologic types are dominant in the Garnet Mountain quadrangle: (1) crystallized lava flows of basic andesite composition intercalated with flow breccias, and (2) stratified volcanic breccia of basic andesitic to more acidic composition.

<u>Lava flow units</u>.--The predominant rock type is black to dark-gray dense finely crystalline moderately porphyritic basic andesite. Phenocrysts are chiefly plagioclase, augite, and hypersthene. Plagioclase occurs in various sizes down to fine microlites in some specimens. Alignment of microlites is common, and flow banding on a megascopic scale can be recognized in many places. Composition of the phenocrysts ranges from An_{47} to An_{59}. Zoning is present, but it is not strong in most grains. Some crystals are corroded. The augite is very pale green, generally nonpleochroic, and commonly twinned on the (100) plane. Hypersthene phenocrysts are pleochroic from pale green to light tan or fawn. A few hypersthene crystals are rimmed with augite. Hornblende phenocrysts have developed in a few specimens of the rock. The matrix of the andesite contains finely crystalline pyroxene, plagioclase, and opaque minerals, which appear to be principally magnetite. Alteration products include fibrous serpentine, chlorite, sericite, hematite, and calcite. Plate 2, figure 1, illustrates the typical texture of the rock.

Chemical analysis of this rock (Table 1, sample A) indicates a lower silica content, 55.12 percent, than the average andesite, 59.59 percent (Daly, 1933), and a moderately higher content of alkalis. Additional samples from the Garnet Mountain and Fridley Peak quadrangles were analyzed for SiO_2 content. They range from 50.7 to 58.4 percent SiO_2, indicating an andesitic composition (more than 52 percent SiO_2) for most of the flow material (Williams, Turner, and Gilbert, 1954, p. 43). Some of the rock may be termed basalt.

The lava sequence consists of many superimposed individual flows. Some flows exceed 100 feet in thickness; others are much thinner. Flows are marked by red, oxidized upper portions, which in places appear somewhat weathered. In a particularly well exposed sequence on the north side of Squaw Creek in sec. 8, T. 5 S., R. 6 E., at least six distinct flows can be studied in continuous exposure. Tops of flows are irregular in detail, but the flows are parallel or near-parallel on a large scale.

The flow material comprises three intergrading types: (1) massive crystalline columnar-jointed rock; (2) broken blocky densely crystalline to vesicular material with many irregular joints; and (3) flow breccia consisting of lenses and fragments of vesicular and nonvesicular andesite similar in composition to the flows, set in a reddish to gray matrix of finely ground lithic fragments and labradorite and pyroxene crystals. The three types may intergrade either vertically or laterally within a flow over a few tens of feet. Breccia becomes generally more abundant near the tops of flows. The relations indicate that lava, as it flowed, tended to crumble into rubbly, oxidized blocks, particularly near the upper surfaces of flows.

Stratified breccia.--Several laterally extensive beds of crudely stratified volcanic breccia are interlayered with the sequence of flows and flow breccias. These layers range from a few tens of feet to several hundred feet in thickness and dip eastward along with the rest of the volcanic sequence. Of the total volcanic pile, stratified breccias are subordinate in quantity to flows.

Fragments within the breccia are heterolithologic, including several volcanic types. Many of the fragments are similar in composition and texture to the flows, but oxidized and unoxidized or vesicular and nonvesicular types may occur close together. Blocks of light-colored acidic to intermediate rock of volcanic or shallow intrusive origin are also present in some beds. Few nonigneous fragments are present. The blocks are angular to subrounded; many are as much as 2 feet in diameter, and some exceed 5 feet. Locally the larger boulders are crudely concentrated in lenses. The matrix of the breccia is fragmental, contains crystals and small lithic particles, and ranges from dark brown to light gray depending chiefly on the ratio of dark to light igneous fragments. Stratification of the breccia is easily seen on a scale of tens of feet, but is poor to good on a small scale.

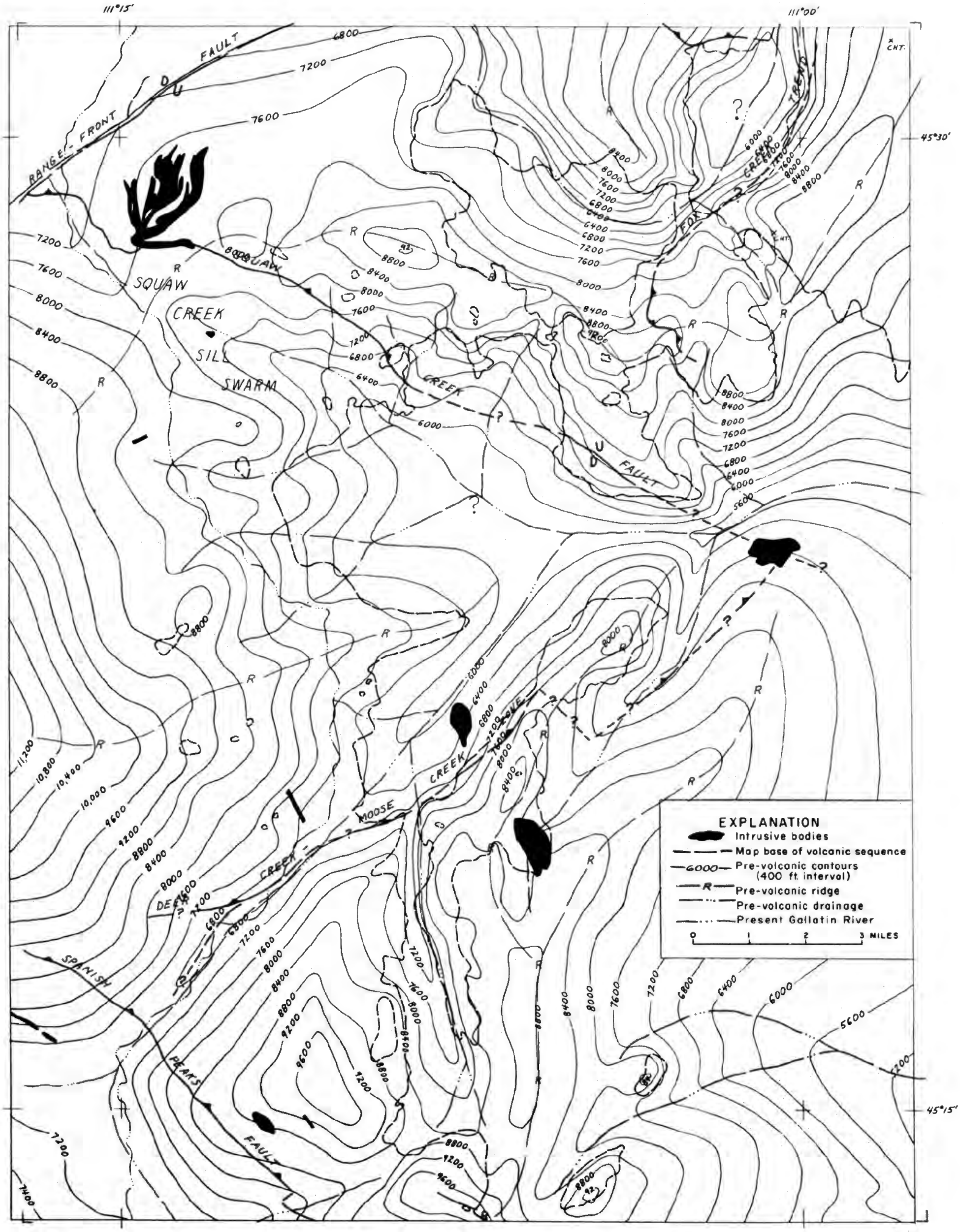


Figure 2.-- Major drainages, ridges, and contours of pre-volcanic topography, and major structural features, Garnet Mountain quadrangle and parts of adjacent quadrangles.

Beds exposed along upper Squaw Creek are typically unstratified on a small scale, and contain poorly sorted angular to subangular fragments of dark andesite in a dark-brown fragmental matrix rich in augite and hypersthene crystals similar to the pyroxenes of nearby flows (pl. 2, fig. 2). Interbedded with flows and flow breccia are two distinct crudely layered 200-foot beds nearly 1,000 feet apart stratigraphically, which are interpreted to be principally of volcanic mudflow origin. The compositional similarity between breccia fragments and nearby flows suggests that the latter may be the source of the fragments. Large size of fragments (5 feet in diameter) so far from any apparent source makes an explosive (air-deposited) origin unlikely. Near-uniform thickness of beds and intercalation with flows militate against development by talus-slope deposition or by subsurface intrusion. Angularity of fragments and general lack of small-scale stratification are not consistent with deposition predominantly by water. Variability in degree of oxidation and vesicularity among adjacent fragments contrasts with the greater homogeneity of fragments in the flow breccias. All these features, considered together, are most consistent with deposition by laharic mudflows. Similar breccias are much more extensive to the east in the Fridley Peak quadrangle.

In the Sentinel Peak-Windy Pass area (sec. 22, 28, and 33, T. 6 S., R. 5 E.) there are finely stratified light-gray breccia beds. These beds contain, in addition to dark andesite boulders, many fragments of acidic volcanic and intrusive igneous rock. Some pumice is present. Many fragments are rounded or subrounded; some individual lenticular zones would be better termed conglomerate. Lenses containing volcanic sandstone and siltstone suggest that water has played a considerable role in sorting this material. Similar thin stratified lenses occur locally within poorly stratified breccia beds such as those at Squaw Creek; perhaps conditions fluctuated between viscous mudflows and sediment-laden stream and sheetwash transport. Fall of ash may have occurred periodically to produce some local fine tuffaceous lenses.

Major volcanism in the quadrangle may have begun as early as latest early Eocene according to evidence on dating of spores in the pre-volcanic black shale. Sparse paleontological data in the Crown Butte quadrangle to the south (W. B. Hall, 1961, Unpub. Ph.D. Thesis, Univ. of Wyoming) suggests that the lower part of the volcanic sequence there is middle or possibly late Eocene. A minimum age for major volcanism is suggested by the occurrence of basic andesite fragments in late Miocene sediments of the Yellowstone Valley (Horberg, 1940) and in an area less than 6 miles north of the northwest corner of the Garnet Mountain quadrangle (M. D. Mifflin, 1963, Unpub. M.S. Thesis, Montana State College). In the latter area the late Miocene deposits overlap eroded remnants of volcanic rock identical to some of that in the Gallatin Range. The volcanism may therefore be related in age to that which produced the Eocene "early basic breccia" and related types in the Yellowstone Park-Absaroka region (Dorf, 1960; Hay, 1956; Parsons, 1958).

In summary, prolific extrusions of basic andesite lava flowed out on an irregular erosion surface developed in what is now the northern Gallatin Range. The lava first filled topographic lows and built up a flatter surface on which later extrusions formed. In some places movement of the lava ceased before solidification, but elsewhere motion continued after the mass was essentially solid, causing brecciation. At intervals between or perhaps during flowage of lavas, extensive laharic mudflows transported broken blocks of volcanic rock for many miles. Periodically, water further sorted and stratified the material. Ash fall may have produced some of the finer, tuffaceous lenses.

PRE-VOLCANIC TOPOGRAPHIC PATTERN

Field observation and pattern of distribution of the volcanic materials in the Garnet Mountain quadrangle, as well as in the entire Gallatin Range, indicate that volcanic debris filled and subdued a pre-existing land surface of considerable relief. Present elevations at the base of the volcanic sequence generally range from 6,000 to 9,000 feet, and local relief is as much as 3,000 feet in a distance of two miles. C. C. Bradley (oral communication, 1958) first called these relationships to the senior writer's attention. Figure 2 is an attempt to reconstruct the pre-volcanic topographic pattern. The method involved in construction of the map is described below and is followed by a brief analysis of the significant features disclosed.

Method.--The elevation control used in the contouring of Figure 2 is based on several obvious facts, as follows:

1) At the contact between volcanic sequence and older bedrock, the elevation control is precise within the limits of map accuracy.

2) Away from that contact, under areas covered by volcanic material, the base of the volcanic sequence must be at less than present ground elevation.

3) Away from that contact, in areas denuded of volcanic rock, the base of the volcanic sequence must have been at greater than present ground elevation.

4) Isolated remnants (outliers) of volcanic rock beyond the main area of volcanic cover and isolated exposures (inliers) of pre-volcanic rock within the main area of volcanic cover provide additional critical control.

Obviously the most precise control is at the contact between volcanic rock and older bedrock, and precision decreases with distance either way from such control. Fortunately the present topographic relief is large, and distribution of volcanic rock irregular enough that a well-defined drainage pattern is discernable in the map area.

Analysis of pattern.--Figure 2 depicts the pre-volcanic topographic configuration of the Garnet Mountain quadrangle and small parts of adjacent quadrangles. Total relief, and to a minor extent local relief, has undoubtedly been modified by tilting and warping related to post-volcanic movements on normal faults bordering the Gallatin Range block on the northwest and southeast. It is believed that such modification is slight, however, and that the topographic pattern is essentially unchanged.

Several significant features are apparent on this map, perhaps the most important of which is the drainage that trends west to east across the area that is now the crest of the Gallatin Range. The pre-volcanic Gallatin River flowed northeastward and then turned eastward toward what is now the Yellowstone River valley. This ancient Gallatin drainage was separated from drainage to the northwest by a prominent topographic high now at elevations of 8,000 to 9,000 feet. Another topographic high, now at elevations of 8,000 to 9,600 feet, separated the upper part of the ancient Gallatin from the upper reaches of what is now the Yellowstone drainage. Detailed observations in the map area indicate that smaller tributaries of the ancient Gallatin drainage system are compatible with an eastward direction of flow.

Comparison of the pre-volcanic topography with structures shown in color (fig. 2) reveals that some of the major topographic trends are structurally controlled. In particular, these are apparent:

1) The main northeast-trending fork of the pre-volcanic Gallatin River generally parallels the Deer Creek-Moose Creek thrust zone.

2) The northwest-trending fork of the same river parallels the Squaw Creek fault zone.

3) The arcuate topographic low in the northeast part of the map in part parallels the Fox Creek trend.

The present course of the Gallatin River crosses the Gallatin Range-Spanish Peaks structural block via a deeply-incised canyon that is not structurally controlled, but rather seems to be a result of superposition and antecedance. The pre-volcanic Gallatin drainage was filled to overflowing by volcanic debris, and the river established a course across relatively flat volcanic terrain. Incision into and removal of vast quantities of volcanic material, and subsequently of pre-volcanic bedrock, has brought the river down to its present level, where it flows mainly on Precambrian metamorphic rock. As the river cut downward, differential tilting and warping of the Gallatin Range block proceeded, related to regional uplift and faulting along the northwest and southeast margins of the range. Thus, in part, the depth of incision and the present position of the river are related to antecedance.

TERTIARY INTRUSIVE ROCKS

Igneous intrusive bodies of several compositional types have been emplaced in the form of stocks, dikes, and sills. Some of the bodies cut at least the lower portion of the andesitic volcanic rocks; others are not in contact with them and relative ages are less certain. Most of the intrusive bodies are porphyritic and have characteristics indicating shallow depth of emplacement. The predominant types are (1) dacite porphyry as stocks or irregular domed intrusive masses and dikes, (2) hornblende andesite porphyry and related diorite, principally as sills, and (3) a rhyolitic dike.

Dacite porphyry.--Several intrusive bodies consist of a light-gray fine-grained porphyritic rock, which is more variable in texture and color than in mineralogical or chemical composition. White to cream-colored phenocrysts of plagioclase are distinctive. Under the microscope strong zoning, progressive or oscillatory, may be observed in many crystals. Some crystals show effects of resorption along the borders. Composition of the phenocrysts ranges from andesine to calcic oligoclase. Swarms of small plagioclase laths and microlites abound, particularly in chilled rock near contacts, where they exhibit a well-developed flow structure.

Biotite and hornblende phenocrysts are common but subordinate to plagioclase in size and number. Biotite crystals, which are pleochroic from light to dark brown, are fairly fresh, but hornblende has been considerably altered, especially in the portions of rock that were cooled slowly. Many crystals are rimmed by fine opaque grains, principally magnetite and hematite. The embayments in corroded crystal margins are in places filled with small plagioclase laths, suggesting alteration of the hornblende by reaction during magmatic crystallization. Pleochroism ranges from light to dark green in fresh hornblende, but is commonly reddish brown in altered crystals. The matrix of the rock grades from glassy in rapidly chilled border facies to aphanitic, wholly crystalline in slowly cooled portions. The color of the matrix may be light gray, dark gray, or reddish gray, apparently depending on the rate of cooling and degree of oxidation of the rock.

Analyses indicate that samples from the various intrusives are chemically very similar (Table 1, specimens B, C, D, E). The rocks contain about 65 percent SiO_2. They are somewhat sodic (4.25 to 5.83 percent Na_2O), and CaO tends to vary inversely with Na_2O. The rocks are considerably more acidic than the andesitic flows.

Four major intrusive bodies of dacite porphyry have been mapped in the quadrangle (pl. 1). They are termed the northern and southern Moose Creek, upper Squaw Creek, and Shenango Creek intrusive masses.

The northern Moose Creek intrusive body is exposed in sec. 32, T. 5 S., R. 5 E., and sec. 5, T. 6 S., R. 5 E. It has an oval surface exposure, elongate north-northwest, and is about 3/4 mile long. The southeast contact dips steeply outward, and Tertiary volcanic flows and breccias have been turned up parallel to the contact. The intrusive rock therefore postdates at least some of the volcanic rocks and seems to have beem emplaced forcibly. Flow structure in the intrusive rock is horizontal near its center and dips downward and outward on the east and west sides of the body, suggesting that the domed roof of the intrusive mass was not far above the present land surface. The rock is medium to dark gray or reddish gray and contains phenocrysts of plagioclase (principally calcic andesine), hornblende, and subordinate biotite.

The southern Moose Creek intrusive body (sec. 9, 10, 15, and 16, T. 6 S., R. 5 E.) is larger in surface exposure than the northern Moose Creek body. The southeastern contact, where volcanic rocks are transected, is steep; flow structure in the intrusive rock parallels this contact. Along the flatter northeast margin flow structure is also parallel to the contact and to upturned Cambrian sedimentary beds. Columnar jointing normal to flow structure is common in much of the intrusive rock. The features indicate a forcible emplacement and flowage of partly crystallized magma along the walls of the body. The local presence of a chilled zone inside a coarser grained border facies suggests repeated injection. The intrusive rock is light gray and contains phenocrysts of sodic andesine, biotite, and hornblende. The matrix contains pockets of equigranular quartz.

The outcrop of the upper Squaw Creek intrusive mass (sec. 17 and 20, T. 5 S., R. 6 E.) is shaped like an irregular ring or doughnut. The steeply-dipping body cuts through volcanic flows and breccias, which are fairly high in the exposed sequence. Volcanic rocks are also exposed inside the intrusive ring. The ring ranges in width from dikes 100 to 200 feet thick to irregular masses $\frac{1}{4}$ mile in outcrop width. On the north and east sides the dip is steeply inward, and just outside the north margin of the complex two thin dikes dip nearly parallel to the main intrusive mass. Flow structure in many places in the main intrusive body and in subsidiary dikes is parallel to the contacts. The relationships suggest that the intrusive body is a modified cone sheet complex, which intruded upward along one major cone-shaped fracture and portions of subsidiary fractures, perhaps widening out irregularly from the original channel. The intrusive mass lies on the projected trend of the Squaw Creek fault (pl. 1), which may have controlled the emplacement of the body. Petrographically the rock is very similar to the southern Moose Creek intrusive body.

Table 1.--Chemical and normative analyses of igneous rocks.

Chemical analyses[1/] Weight percent	A	B	C	D	E	F
SiO_2	55.12	66.82	65.32	67.64	64.00	55.64
Al_2O_3	18.49	16.15	15.66	15.46	17.95	19.35
Fe_2O_3	5.09	3.37	3.06	2.83	2.36	4.51
FeO	3.50	0.38	0.98	0.65	1.25	3.23
MgO	2.80	0.61	1.48	0.75	1.12	2.06
CaO	6.14	2.88	2.88	2.54	3.28	7.18
Na_2O	4.06	4.96	5.80	5.83	4.25	4.34
K_2O	2.81	2.81	2.62	2.85	3.09	1.92
Total	98.01	97.98	97.80	98.55	97.30	98.23
Normative minerals (CIPW)						
Quartz	3.9	20.2	14.4	17.2	18.5	5.4
Orthoclase	16.6	16.6	15.5	16.9	18.3	11.4
Albite	34.4	42.0	49.1	49.1	35.9	36.7
Anorthite	23.8	13.5	8.9	7.6	16.3	27.6
Corundum	--	--	--	--	1.7	--
Wallastonite	2.7	0.4	2.3	2.1	--	3.4
Enstatite	7.0	1.5	3.7	1.9	2.8	5.2
Ferrosilite	2.2	--	--	--	0.3	2.2
Magnetite	7.4	1.2	3.2	2.1	3.3	6.5
Hematite	--	2.5	0.9	1.4	--	--

[1/]Warner Laboratories, Inc., analysts.

A. Andesite flow, Squaw Creek near junction with West Creek.
B. Dacite porphyry, northern Moose Creek intrusive.
C. Dacite porphyry, southern Moose Creek intrusive.
D. Dacite porphyry, upper Squaw Creek intrusive, northeast portion.
E. Dacite porphyry, Shenango Creek intrusive.
F. Diorite, Storm Castle intrusive complex.

The Shenango Creek intrusive mass (sec. 15, 16, 21, and 22, T. 4 S., R. 4 E.) cuts Precambrian rocks and lies against Paleozoic rocks across the Squaw Creek fault. It is an irregular body with several long arms extending northward and eastward generally parallel to the foliation of the Precambrian metamorphic rocks. The color ranges from light gray to dark gray to tan. Phenocrysts are mainly calcic oligoclase and biotite, with subordinate hornblende and quartz (pl. 2, fig. 3 and 4).

Three of the four intrusive masses transect at least a part of the Tertiary volcanic sequence and are thus definitely younger than these volcanic rocks, but boulders of similar intrusive rock are present in the volcanic breccia high in the sequence near Sentinel Peak. Perhaps some of the intrusions predated the later stages of volcanism.

The emplacement of the intrusive bodies seems to be related to major faults in the area. (See discussion on Structural Geology.) Similar-appearing intrusive rocks are exposed on Big Creek, Mill Creek, and other tributaries of the Yellowstone River east of the Garnet Mountain quadrangle. Investigation of these areas is underway, and results obtained there should aid in an understanding of relationships of the Tertiary intrusive and extrusive rocks of the entire region.

Hornblende andesite porphyry.--Sills of dark-gray andesite porphyry have intruded the Paleozoic-Mesozoic block in the northwest part of the map area. The sills are so numerous and so thin that they could not be shown at the map scale used. A dike of similar material intrudes Precambrian rock in the NW$\frac{1}{4}$ sec. 9, T. 5 S., R. 4 E. Sills are particularly abundant in the vicinity of Storm Castle, where all formations from Cambrian to Cretaceous have been invaded. Sill thickness ranges from a few inches to about 100 feet. Some of the sills in the Meagher limestone were studied by Hawkins (1956, Unpub. M.S. Thesis, Montana State College), who described chemical reactions between the sills and the surrounding limestone. He concluded that the limestone had contaminated the sills near their borders but that most of the space occupied by the sills was attained by mechanical displacement of the host rock.

The sills contain phenocrysts of hornblende, plagioclase, and locally augite. The matrix is mainly crystalline and ranges from dark gray to greenish gray. Hornblende phenocrysts may exceed 1 cm in length and are pleochroic in blue green, olive green, and light brown. Some hornblende is altered to mixtures of chlorite and calcite. Plagioclase phenocrysts commonly range from 0.5 to 2 mm in size, and many are well zoned. Composition of the larger crystals is principally calcic andesine. Augite is very pale green, nonpleochroic, and commonly rimmed by secondary calcite. Calcite is abundant in the sills, and some occurs as large rhombs. Local calcium enrichment by assimilation of limestone is suggested. Other minerals present in the rock include magnetite, pyrite, apatite, hematite, sericite, and quartz. Several of the sills contain scattered xenoliths of Precambrian gneiss, amphibolite, and schist.

Diorite.--A small stocklike body having a surface exposure about 0.1 mile in diameter lies in close field relationship with the hornblende andesite porphyry in the NE$\frac{1}{4}$ sec. 34, T. 4 S., R. 4 E. It has intruded the sedimentary sequence at least through the Lodgepole Formation. The texture is phaneritic, grain size ranging from 0.1 to 2mm. A modal analysis by the point count method is presented in Table 2. Plagioclase and hornblende are euhedral to subhedral. Plagioclase is principally calcic andesine; however, extreme zoning in some crystals suggests a considerable variation locally from this composition. Orthoclase and quartz are mainly interstitial (pl. 2, fig. 5).

Table 2.--Modal analysis of Diorite.

Plagioclase	68.8%
Orthoclase	5.6
Quartz	6.9
Hornblende	12.1
Opaque minerals	3.3
Calcite	1.6
Chlorite	1.4
Apatite	0.1
Sericite	0.1

Analysis based on 1054 points spaced over approximately 400 mm^2 of thin section.

A potassium-argon age determination on the hornblende andesite porphyry ($103.5 \pm 6.8 \times 10^6$ yr: Geochron Laboratories) received while this publication was in press suggests that this rock and the diorite may be Middle Cretaceous rather than Tertiary.

Rhyolite.--A rhyolitic dike crops out on the west side of Gallatin Canyon north of Asbestos Creek in sec. 11 and 12, T. 6 S., R. 4 E. Large phenocrysts are generally lacking. Sodic oligoclase laths and microlites, opaque particles, and sparse biotite and quartz grains are scattered through a glassy to cryptocrystalline matrix. Flow alignment of the crystals is common. The rock may be related to rhyolite that crops out farther up the Gallatin River south of the quadrangle (Hall, 1961, Unpub. Ph.D. Thesis, Univ. of Wyoming; Peale, 1896).

S T R U C T U R A L   G E O L O G Y

REGIONAL SETTING

Intelligent analysis of structural features in the Garnet Mountain quadrangle requires a presentation in context with regional relationships. The dominating structural features of nearby areas are northwest-trending faults of major displacement. Significant, but less obvious, north- and northeast-trending structures are also present (fig. 3). The faults and associated folds disrupt a thin sedimentary sequence and underlying basement rocks in what is generally termed a shelf province. Over-all patterns and age of deformation in the Rocky Mountain region indicate a gross eastnortheast compressive stress during Laramide orogeny. Evidence in adjacent south-central and central Montana indicates recurrent minor Paleozoic and Mesozoic movement on present-day major structural features (Alpha and Fanshawe, 1954; Sonnenberg, 1956). It is generally believed that old structural trends in the basement and structures related to orientation of stress systems during the Cretaceous-Early Tertiary Laramide orogeny are combined in the existing deformational patterns.

In such a regional situation one might expect to find local evidence of old differential movements on some of the structural trends in the Garnet Mountain quadrangle, and considering the gross stress pattern in the Rocky Mountains, evidence of some strike-slip movement on the northwest-trending faults should be found.

LOCAL STRUCTURE

Northwest-trending faults.--Two major northwest-trending faults separate the quadrangle into three crustal blocks. The Squaw Creek fault extends diagonally across the north half of the map area, and the Spanish Peaks fault crosses the southwest corner of the area (fig. 4).

Squaw Creek fault: The Squaw Creek fault is the southeast extension of what has been called the Cherry Creek fault northwest of the map area (Samuel Kozak, 1961, Unpub. Ph.D. Thesis, State Univ. of Iowa). The Cherry Creek fault is separated from the Squaw Creek fault by later displacement on the Gallatin Range frontal fault (fig. 3).

In the map area the Squaw Creek fault trends about N. 50° W. and dips steeply northeast or is vertical. In most places along its trace the fault has a reverse relationship. Precambrian metamorphic rock on the upthrown north side lies against all stratigraphic units from Cambrian to Cretaceous on the downthrown side. Minimum stratigraphic displacement is in excess of 4,500 feet; the actual dip-slip component of movement may exceed 6,500 feet. Related smaller reverse faults of similar strike along the

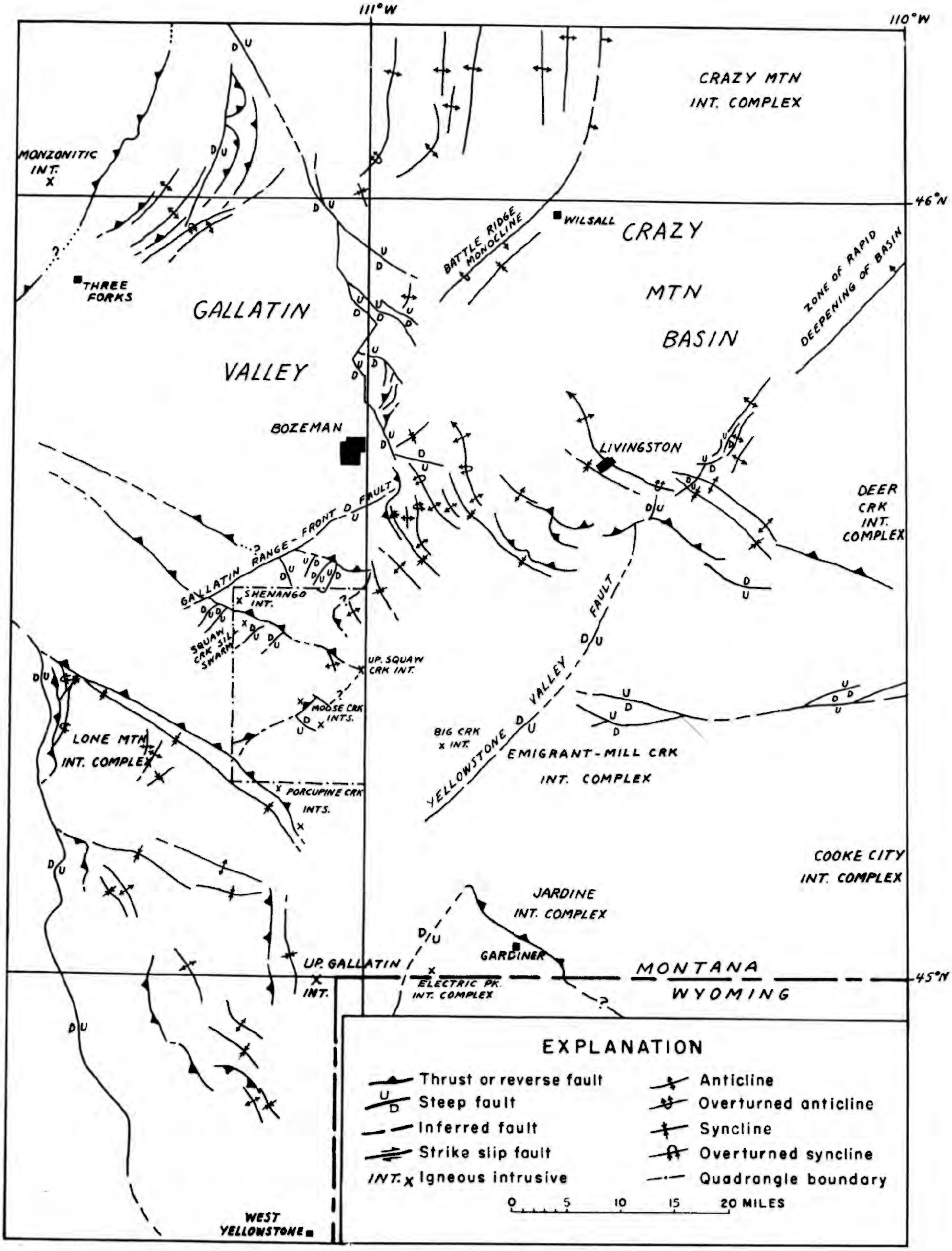


Figure 3.--Major structural features of the region around Garnet Mountain quadrangle.

lower part of Squaw Creek distribute the displacement on several fractures (cross section A-A', pl. 1). Minor transverse faults in the vicinity of Garnet Mountain and the Squaw Creek Ranger Station seem to be related to differential displacement in the downthrown block or to emplacement of the many sills of that area.

The Squaw Creek fault cuts obliquely across folds that trend more northerly at Timber Butte (sec. 10 and 11, T. 5 S., R. 5 E.). Also, two of the larger cross faults near Garnet Mountain and several similar northeast-trending faults beyond the edge of the quadrangle are arranged en echelon along the Squaw Creek fault. The geometric arrangement of these features could be related to a stress couple produced by a left lateral component of strike-slip movement on the Squaw Creek fault (fig. 3).

The Squaw Creek fault is covered by the Tertiary volcanic sequence and apparently also by the late early Eocene siltstones; it may have acted as a conduit for the Shenango Creek and upper Squaw Creek intrusive bodies. The youngest stratigraphic unit displaced by movement on the Squaw Creek fault is the Colorado Group. The age of major fault movement, therefore, cannot be determined more precisely than Late Cretaceous to early Eocene. Too little detailed stratigraphic work has been done along the fault to indicate the nature of earlier differential movements, if any. Later displacement, suggested by offset of mid-Cenozoic strata and a very young (Pleistocene?) erosion surface, has been observed about 25 miles to the northwest on the Madison River (T. 2 S., R. 1 E.). There the downthrow of these younger materials (northeast side of fault) is opposite to that produced by earlier movement in the pre-Cenozoic bedrock. Such later movements are not indicated in the map area.

Spanish Peaks fault: The Spanish Peaks reverse fault forms the southwest boundary of the prominent northwest-trending Spanish Peaks. General alignment of the fault with a similar major fault at Gardiner, Montana, suggests that the two may be one and the same, although proof is lacking because the intervening area is covered by the Tertiary volcanic sequence for more than 15 miles (fig. 3).

The fault places Precambrian metamorphic rock on the upthrown side against everything from basal Cambrian beds to the lower part of a Paleocene and possibly Late Cretaceous unit that occupy a broad synclinal area adjacent to the southwest part of the Garnet Mountain quadrangle. Relationships along the fault and thicknesses of stratigraphic sequences (4,500 feet Cambrian to Lower Cretaceous; 8,000 feet Upper Cretaceous undifferentiated; 6,000 feet Paleocene and possibly Upper Cretaceous--W. B. Hall, 1961, Unpub. Ph.D. Thesis, Univ. of Wyoming) suggest a possible stratigraphic displacement of 13,500 feet. Hall makes a more conservative estimate of 10,000

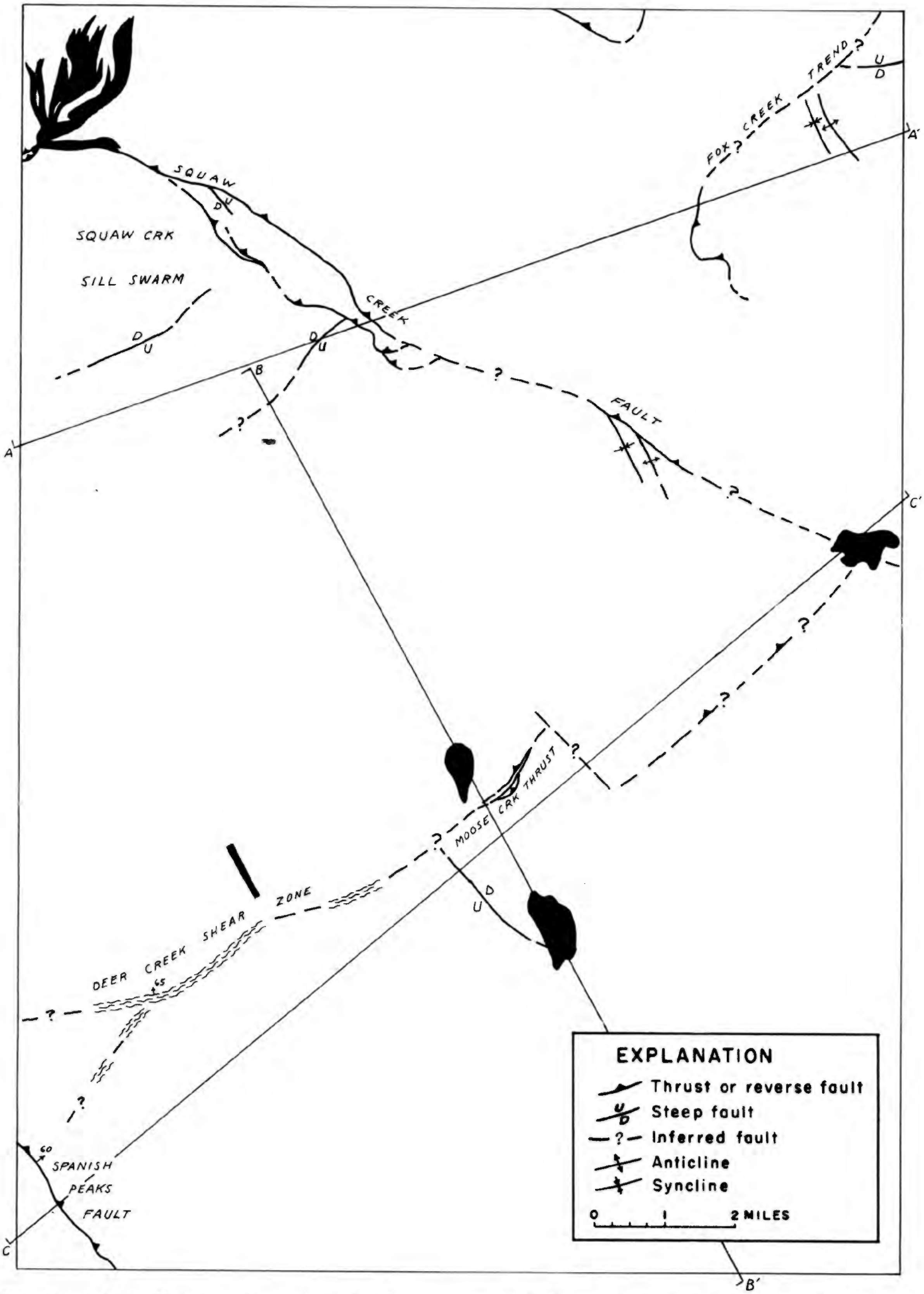


Figure 4.--Main structural features of Garnet Mountain quadrangle.

feet of displacement. The fault is obviously one of major proportions on which the dominant movement seems to be dip-slip (cross section C-C', pl. 1).

A little more than 2 miles of the fault trace is exposed in the map area, and maximum stratigraphic displacement is where Precambrian rock rests against Mission Canyon Limestone (pl. 1). The reverse fault dips about 60° northeast at the Gallatin River. In sec. 29, T. 6 S., R. 4 E., just west of the map area, a minor diagonal strike-slip fault in the footwall block suggests drag related to a small component of left lateral strike-slip motion on the main fault.

South of the Garnet Mountain quadrangle the Spanish Peaks fault is buried by the Tertiary volcanic sequence and there it also seems to have served as a locus for several Tertiary igneous intrusions. In the same general area the lower part of the Livingston(?) Formation (Paleocene and possibly Upper Cretaceous) is in the fault contact with Precambrian metamorphic rock, and younger beds in the Livingston(?) are vertical to overturned (map in W. B. Hall, 1961, Unpub. Ph.D. Thesis, Univ. of Wyoming). The Livingston(?) Formation rests unconformably on a thick undifferentiated Upper Cretaceous sequence and is overlain unconformably by the undated Sphinx Conglomerate, which is 3,500 feet thick. The Sphinx has also been folded into a northwest-trending syncline. Therefore, the major fault movement and related folding of beds is post-Late Cretaceous and much of it is probably younger than the Paleocene beds of the Livingston(?) Formation; some of it is even younger than deposition of the Sphinx Conglomerate (Eocene?).

Dating of the latest movement on the Spanish Peaks fault depends upon determination of the age of the Tertiary volcanic sequence. As discussed in the section on igneous geology, evidence in the Garnet Mountain quadrangle suggests that the lower part of the volcanic sequence may be as old as early middle Eocene or latest early Eocene, and sparse paleontological data in Hall's area suggest that the lower part of the volcanic rocks is middle or possible late Eocene. Thus movements on the Spanish Peaks fault probably occurred in several phases from Late Cretaceous to pre-middle Eocene time. More precise dating of orogenic activity in this and nearby areas must await more definitive determination of age of related sedimentary and igneous rocks.

Northeast-trending faults.--Two major northeast-trending fault zones, the Deer Creek shear zone and the Moose Creek thrust zone, seem to be closely aligned, and together with their hypothetical projection toward the northeast under the volcanic cover, divide the block between the Squaw Creek and Spanish Peaks faults into two parts (fig. 4). Another northeasterly trend (Fox Creek trend) in the northeast corner of the map area almost certainly indicates a major fault or fault zone that joins a northwest-trending thrust.

Moose Creek thrust zone: The Moose Creek thrust zone and associated drag relationships are well shown in sec. 4, 5, and 8, T. 6 S., R. 5 E., on and between the forks of Moose Creek. Several northwest-dipping thrust slices involving Precambrian and Cambrian rocks are aligned along a N. 40° E. trend and are parallel to overturned beds in adjacent Paleozoic outcrops. The zone is overlapped by younger volcanic cover but seems to be part of a major northeast-trending zone of structural discordance that includes the Deer Creek shear zone. The northern Moose Creek intrusive body may have been emplaced along the thrust zone.

Relationships of the thrust zone farther northeast are obscured by volcanic rock and landslide debris. In the SW$\frac{1}{4}$ sec. 34, T. 5 S., R. 5 E., a landslide covers what must certainly be a fault between Mississippian and Precambrian rocks. Such a fault must trend northwest and is interpreted here as a tear fault along which the thrust zone of the northeast side is offset more than a mile southeast. Projection of the hypothetical displaced thrust segment farther to the northeast to its intersection with the projected Squaw Creek fault trend could provide a ready explanation for the locus of the upper Squaw Creek intrusive body (sec. 17 and 20, T. 5 S., R. 6 E.).

Paleozoic strata in the overridden block of the Moose Creek thrust zone are cut off by a high-angle, northwest-trending fault in sec. 8, 9, and 16, T. 6 S., R. 5 E. The southern Moose Creek intrusive body seems to have been injected along this fault. The relationships and interpretations described here are shown in cross sections B-B' and C-C' of Plate 1, and on Figure 4.

Deer Creek shear zone: The Deer Creek shear zone lies directly on line to the southwest of the Moose Creek thrust zone. The trace is entirely within Precambrian rock but is believed to be an extension of the thrust zone. The Precambrian rocks are extensively sheared in a zone as much as 200 yards wide, and shear planes dip about 65° north where part of the zone curves to a more westerly trend on Deer Creek.

Fox Creek trend: The Fox Creek trend, in the northeast corner of the map area, is believed to indicate a major northeast fault that has not yet been exhumed from beneath the volcanic cover. Evidence suggesting a buried fault includes (1) close proximity of Precambrian and Mississippian rocks in sec. 18 and 19, T. 4 S., R. 6 E.; too close to accomodate the normal intervening stratigraphic section; (2) vertical dips in adjacent Paleozoic strata in sec. 8 and 17, T. 4 S., R. 6 E.; and (3) southeasterly overturning of Paleozoic strata along the same trend just northeast of the quadrangle.

To the southwest the Fox Creek trend merges with a northwest-striking thrust fault. It is not known whether the juncture of the two is an intersection or simply joining at a right-angle corner, but the latter relationship seems more likely because

(1) beds in the area north of Mount Blackmore strike northwest and dip northeast, whereas close to the Fox Creek trend they are sharply bent into an overturned westward-dipping attitude; (2) folds in the same area trend northwest and the ends close to the Fox Creek trend are overturned toward the east as though by drag along a major fault; and (3) the nearest Paleozoic outcrops northwest of the Fox Creek trend show no evidence of northwesterly folding. The Fox Creek trend therefore is interpreted as a buried tear fault that merges with a thrust fault to the southwest.

Post-volcanic structural movement.--Volcanic rocks of the Garnet Mountain quadrangle were probably involved in very little differential movement, either folding or faulting. Dips are mainly gentle to the east or southeast in the greater part of the area, and to the north in the northernmost part of the area. Locally at or near the base of the volcanic sequence there are steeper dips, but these seem to be related to deposition of volcanic material on steep topographic slopes. Minor faults were mapped in sec. 1, T. 5 S., R. 5 E., and in sec. 17, T. 5 S., R. 6 E. The change from easterly to northerly dips in the northernmost part of the quadrangle seems to be related to a pre-volcanic topographic divide that extended across the northern part of the map area (fig. 2).

Folding and faulting had essentially ceased in the Garnet Mountain quadrangle prior to deposition of the volcanic sequence, that is, probably prior to middle Eocene time.

Summary of structural relationships.--In summary, the dominating structural features of the map area are those characteristic of the regional trends shown on Figure 3, namely northwest faults of major displacement with allied features, and northeast-trending faults of various character. Major structural movements probably occurred from Late Cretaceous to just before middle Eocene time and as several separate phases within that time interval. No definite evidence was found to suggest that movements on the northeast trends were of a different vintage than those of the northwest trends. Folding and faulting within the map area effectively ceased prior to deposition of the volcanic sequence; however, known later movement on normal faults along the northern side of the Gallatin Range and along the east side of the Yellowstone River south of Livingston (fig. 3) suggests that the Gallatin Range may have been tilted southeastward a few degrees by these later movements.

MINERAL DEPOSITS

Principal developed resources of the Garnet Mountain quadrangle are mica and asbestos. Of lesser importance are small copper prospects that occur in several localities. Intensified exploration may uncover additional quantities of asbestos in this or adjacent quadrangles; possibly additional mica deposits may also be found. The most promising presently developed properties are the Thumper Lode mica mine and the Karst asbestos deposit.

Thumper Lode mica mine.--The Thumper Lode mica mine is located in the NE$\frac{1}{4}$ sec. 30, T. 4 S., R. 5 E., at 8,300 feet elevation on the north slope of Squaw Creek canyon. The property is accessible from Gallatin Gateway via a logging road that crosses the Bear Creek-Squaw Creek divide. The property is owned by W. T. Barham, Dan Barham, Ray Barham, Wessley Atchison, and Walter Atchison. Small quantities of mica were shipped to the federal buying station at Custer, South Dakota, in 1954 and from 1956 to 1962 (Minerals Yearbook).

The mica occurs in a pegmatite within the Precambrian sequence of granitic gneiss, schist, quartzite, and amphibolite. The pegmatite is broadly tabular in shape, striking N. 80° E., and dipping on the average 50-55° NW. Dips are locally variable, however; at a roll in the footwall contact the dip changes from 30 to 70°. Contacts are roughly concordant with the foliation of the gneiss but locally transect it.

The pegmatite has been exposed by underground workings for 200 feet horizontally along its length. Its thickness varies and is about 23 feet where measured in the adit. In addition to the adit crosscutting the body and the drift parallel to its length, raises and winzes have been driven. Above the drift level, several raises extend up the dip. The raises are heavily timbered in part, and some caving has occurred. Two raises reach the surface. Two winzes extend down the dip of the body from drift level. These winzes were flooded at the time of examination. In addition to the underground workings, surface bulldozing above the adit level has exposed the pegmatite in several places. Because the hillside slopes southward and the pegmatite dips northward, adits driven below the present main level would have to penetrate a considerable amount of country rock before reaching the body.

The pegmatite is distinctly zoned (fig. 5). The zones, lithologic units of contrasting texture and mineral assemblage, are roughly concentric and from border to center of the pegmatite are:

1) Border zone: plagioclase-quartz-muscovite.

2) Wall zone: plagioclase-quartz.

3) Outer intermediate zone: plagioclase-quartz-sheet muscovite-biotite-perthite.

4) Inner intermediate zone: perthite-quartz.

5) Core: quartz.

Border and wall zones are each several inches to several feet thick, but the inner zones are thicker. Grain size increases inward from several inches or less in the border zone to a foot or more in the perthite-quartz and quartz zones. The outer zones generally envelop those inside, but the perthite-quartz zone does not completely surround the quartz core. Where observed in the main level, the former zone extends to the east of and seemingly beneath the core. The upper part of the core is in contact with the outer intermediate zone, which makes up the bulk of the pegmatite in the western exposed portion of the body. Near the west end of the workings either the pegmatite branches or a second parallel body is present.

The commercial-grade muscovite occurs principally in the outer intermediate zone but extends into the perthite-quartz zone in places. It appears as thin books and plates, as much as several feet in length. Much of the muscovite is reddish-brown "ruby mica" and is fairly free of cracks, reeves, and staining.

Evidence indicates that the pegmatite developed by crystallization inward from the walls of a fluid-filled cavity. Such evidence includes (1) the consistent sequence of mineral assemblages in zones from border to core, which is similar to that of zoned pegmatites (Cameron and others, 1949, p. 104); (2) the generally concentric nature of the zones; (3) the occurrence of crystals of pegmatite minerals adjacent to and perpendicular to the contact of the body which widen inward from this contact similar to the "comb structure" of hydrothermal veins (Chadwick, 1958, p. 819); and (4) the fact that the outer zones are more regular and conformable with the outline of the pegmatite than the inner ones. As crystallization of the pegmatite proceeded inward, early formed, fairly conformable shells (zones), which reflected the original shape of the cavity, were filled by less regularly concentric units formed from the last residues of crystallization.

Karst Asbestos Deposit.--The Karst asbestos property is located in the SE$\frac{1}{4}$ sec. 35 and SW$\frac{1}{4}$ sec. 36, T. 5 S., R. 4 E., at about 7,000 feet elevation on the west slope of the Gallatin River canyon (pl. 1). Though discovered near the turn of the century, the property was first extensively developed in 1935, and asbestos has since been shipped from time to time from the Karst pit. During part of this period a gravity overhead tramway carried the ore to a small mill near river level. The processed asbestos was trucked to Gallatin Gateway and shipped from there by rail. At present the property is owned by Interstate Products Co., Inc., of Billings, Montana. The deposit has been described by Perry (1948) and T. L. Wilson (1948, Unpub. B.S. Thesis, Montana School of Mines). Richard Marvin (1952, Unpub. M.S. Thesis, Montana School of Mines) mentions the deposit, as well as other asbestos localities in the Gallatin canyon area.

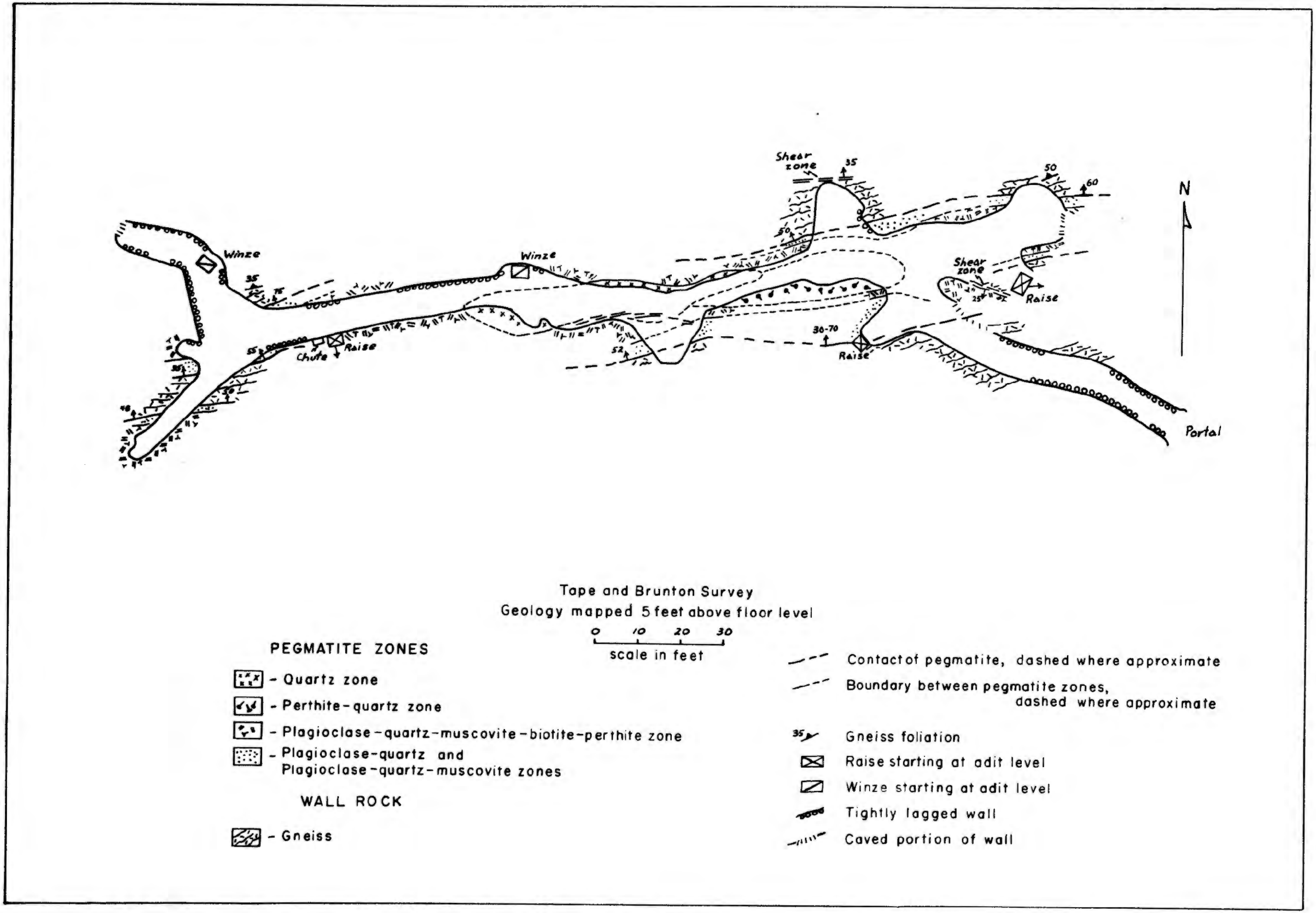


Figure 5.--Plan of adit level, Thumper Lode mica mine.

The asbestos is anthophyllite and has crystallized in a considerably serpentinized peridotite body or bodies within the Precambrain sequence of interlayered feldspar-quartz-biotite gneiss and subordinate mica schist, hornblende schist, and amphibolite. The foliation of the metamorphic sequence strikes northeast; dips are mainly northwest but locally are southeast. Shearing is common within the serpentine and along its borders, and several faults cut the entire sequence.

Two major deposits of asbestos-bearing serpentine have been developed (fig. 6). The eastern deposit, known as the Karst pit, was described by Perry (1948). There is small steeply dipping lens of serpentinized peridotite has been developed by an open pit and exploratory adit. Figures 7 and 8 illustrate the geology of the pit area as mapped by Werner J. Raab (1963, private report, Galaxy Mining Co.). Foliation of the gneiss is distrubed near the serpentine contacts but trends mainly northeast. The body disappears upward near the present surface above the pit. Shear zones follow the serpentine contacts. On the west, a zone of chlorite schist marks the sheared and altered western margin of the peridotite. Faulting may also cut off or displace the body on the north. A quartz-feldspar pegmatite cuts the serpentine near the portal of the adit. Veins of asbestos as much as 2 feet thick transect sheared and altered serpentine. Several prominant steep veins striking N. 20° W. to N. 30° W., have been explored by a short spiral adit, which slopes upward from portal level.

The western deposit, more recently developed, is known as the Montana pit. It lies about 1,600 feet southwest of the Karst pit (fig. 6). Bulldozing has exposed a northeast-trending sill-like serpentinized peridotite body (fig. 9). The hanging-wall contact strikes roughly N. 75° E. in the northeastern part of the exposure and N. 40° E. in the southwestern part. The body seems to dip gently northwestward into the hillside; however, shearing and alteration mask the details of contact relationships. The serpentine body has been exposed for 650 feet along its strike. Excavation has uncovered considerable portions of the hanging-wall contact, but the footwall contact is visible in one location only. The northeastern termination was delineated by magnetometer survey (W. J. Raab, 1963, private report, Galaxy Mining Co.). The body thickens to approximately 150 feet in the central pit area. In the southwestern part of the pit, thickness is uncertain, owing to lack of exposure of the footwall. The body is displaced on the southwest by a fault. One or more additional faults cut the serpentine mass, and another fault may lie between the Montana and Karst pits. In the Montana pit, asbestos veins have varying attitudes within the serpentine and are as much as 2 feet in width. Most asbestos veins are 1 to 6 inches wide. Veins commonly intersect and may pinch out or increase rapidly in width, widening in places to large masses of matted fibers. Fibers in veins are mainly oriented perpendicular to the walls but may be

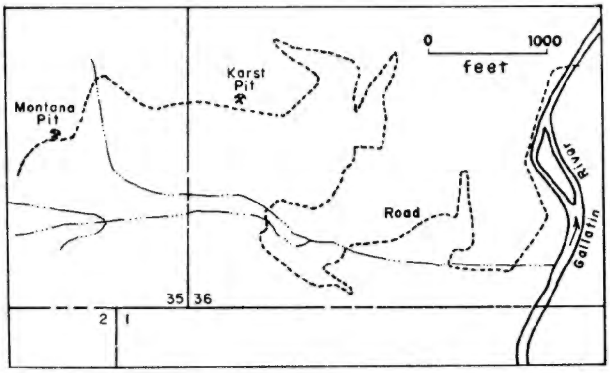


Figure 6.--Sketch map of Karst asbestos deposit.

bent toward parallelism, owing to deformation during or after vein development. The asbestos ranges from soft and silky to hard and splintery. Soft fibers tend to be more abundant in intensively sheared or weathered zones.

X-ray powder diffraction studies performed with equipment of the Montana State College Chemistry Department indicate that the asbestos mineral is anthophyllite. Strong diffraction lines are present at d values (interplanar atomic spacing) of 8.60, 8.02, 3.20, and 3.02 Angstrom units. Under the microscope the material is seen to consist of elongate fibers of moderate birefringence. The

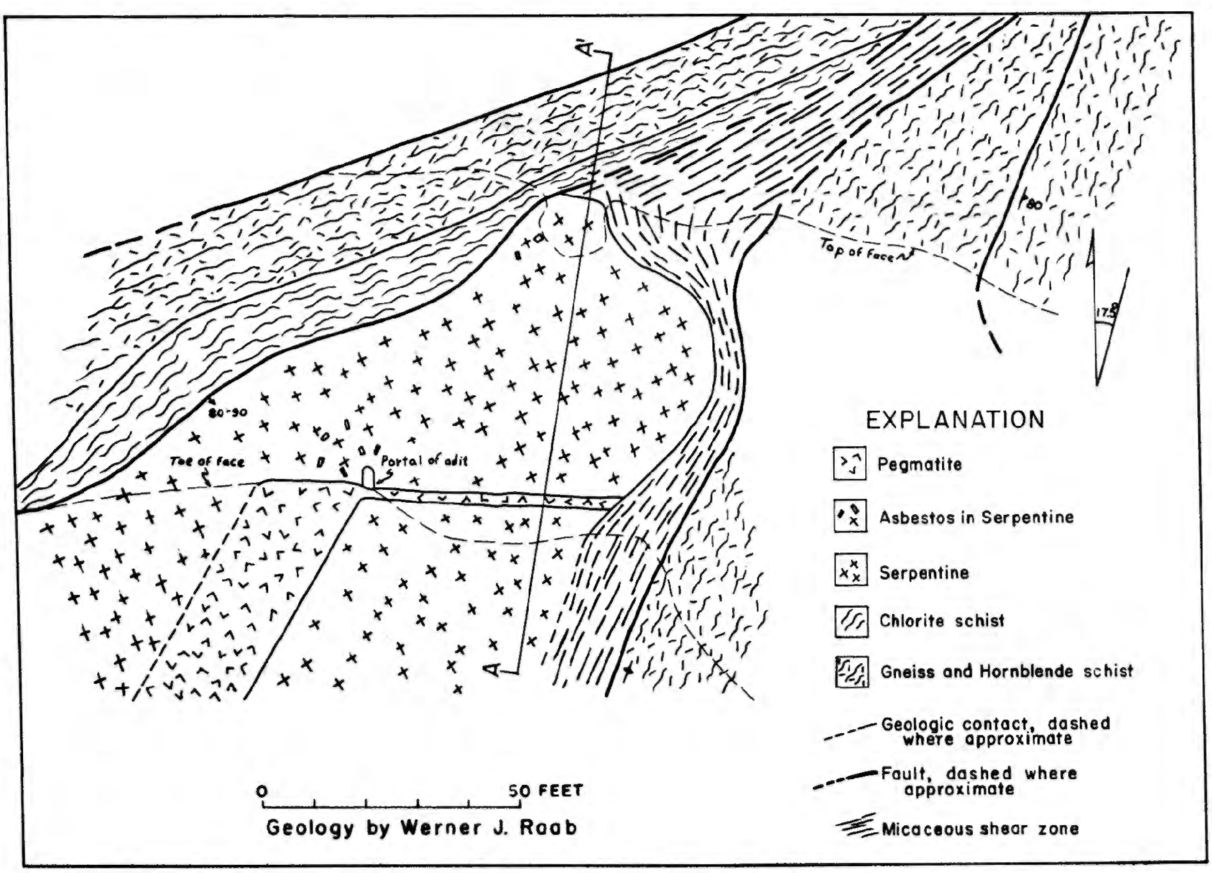


Figure 7.--Geologic map of Karst pit, Karst asbestos deposit.

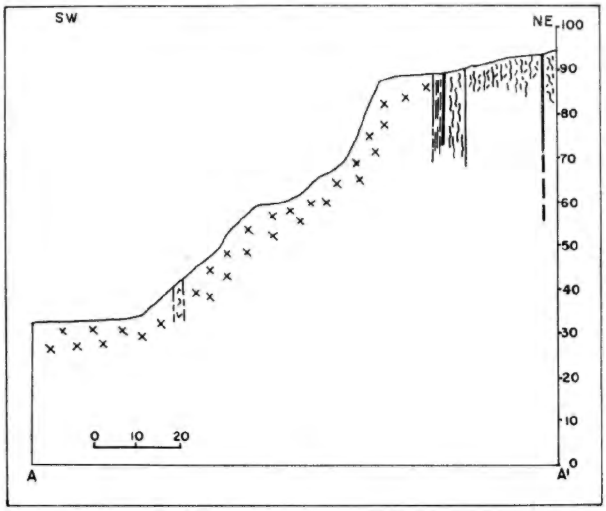


Figure 8.--Geologic section A-A'; Karst pit, Karst asbestos deposit.

smaller fibers lying with the c axis parallel to the microscope stage extinguish parallel to the cross hairs. N_z is approximately 1.632. Thin sections illustrate the alteration of pyroxene to antigorite (pl. 2, fig. 6) and development of fibrous anthophyllite within the antigorite. A chemical analysis of the asbestos (Wilson, 1948, Unpub. B.S. Thesis, Montana School of Mines) reports these percentages: SiO_2=56.06, Al_2O_3=5.84, FeO=9.80, MgO=26.02, CaO=1.22, ign. loss=1.98.

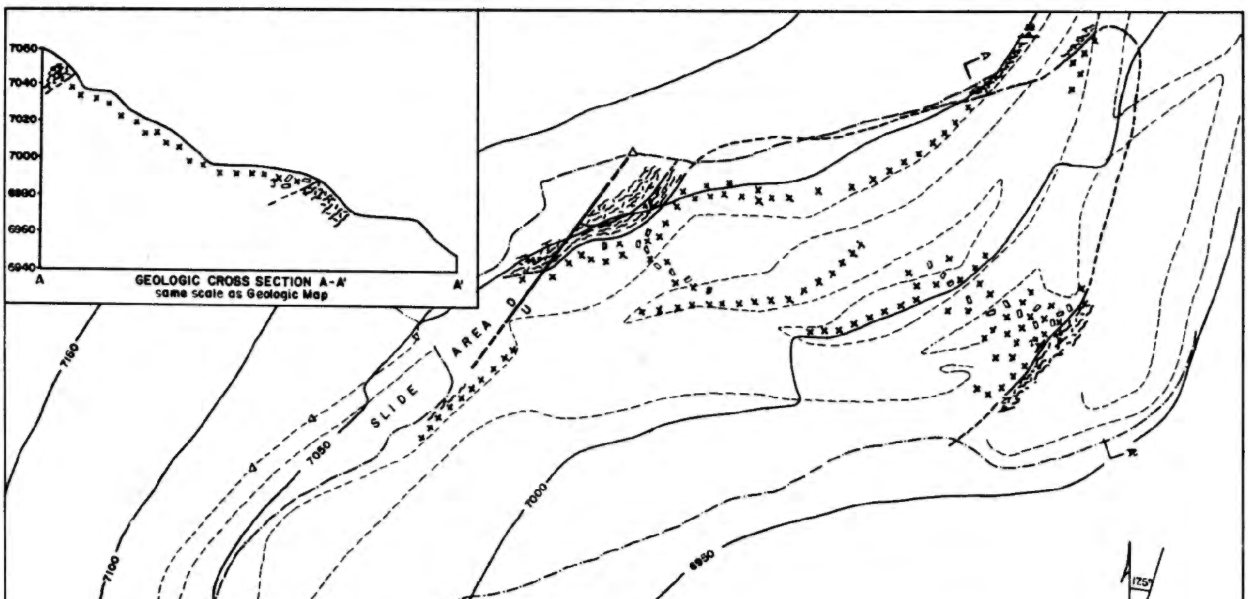
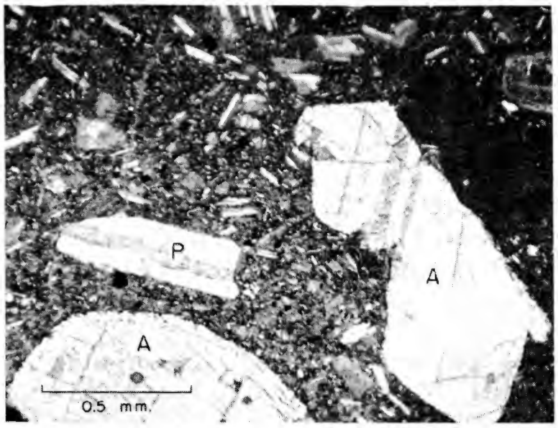


Figure 9.--Map and cross section of Montana pit, Karst asbestos deposit.

Other asbestos prospects.--Small asbestos prospects are scattered in the general area southwest of the Karst deposit. Most of the asbestos is related to small serpentinized basic or ultrabasic bodies. Marvin (1952, Unpub. M.S. Thesis, Montana School of Mines) noted many localities in the north half of T. 6 S., R. 4 E. He described asbestiform anthophyllite and tremolite from that area. Another showing, on Wilson Creek in the SE$\frac{1}{4}$ sec. 18, T. 4 S., R. 5 E., consists of narrow asbestos veinlets in a very small outcrop of serpentine.

Copper.--Minor chalcopyrite is present along the Spanish Peaks fault east of the Gallatin River. Several prospect pits have been excavated in the SW$\frac{1}{4}$ sec. 3, T. 7 S., R. 4 E., on a ridge at 8,300 feet elevation. On this ridge the fault trends generally N. 40° W., but in the vicinity of the prospect pits it bends to a more westerly direction. Chalcopyrite crystals are sparsely scattered through nearly vertical quartz veins as much as 2 feet wide in Precambrian gneiss within 300 feet of the fault. These veins strike N. 80° W., about parallel to the fault at that location. Other minerals present include malachite, pyrite, and hematite.

Copper minerals are present elsewhere along the Spanish Peaks fault and along a shear zone in Precambrian rocks near the mouth of Deer Creek in the NE$\frac{1}{4}$ sec. 22, T. 6 S., R. 4 E.



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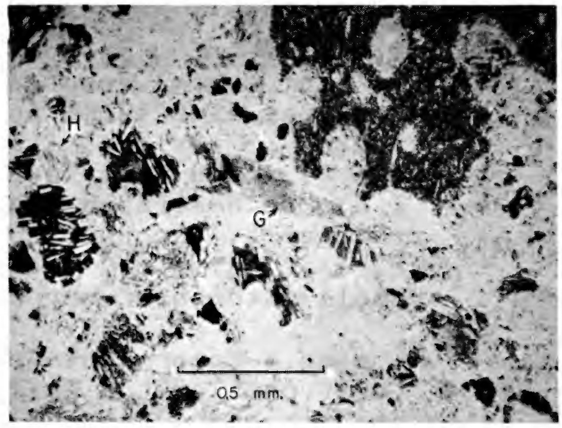

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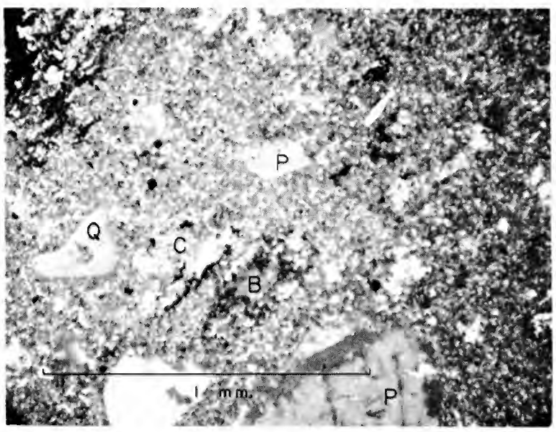

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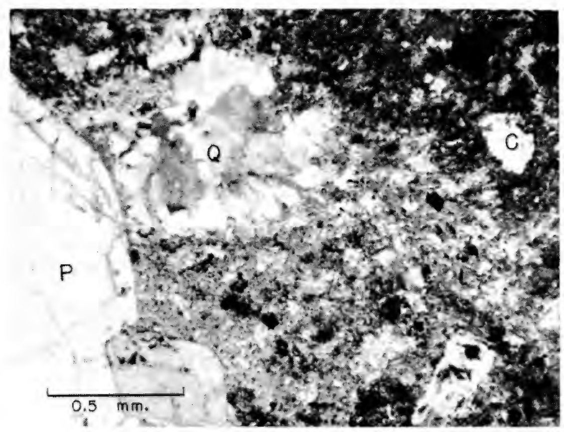

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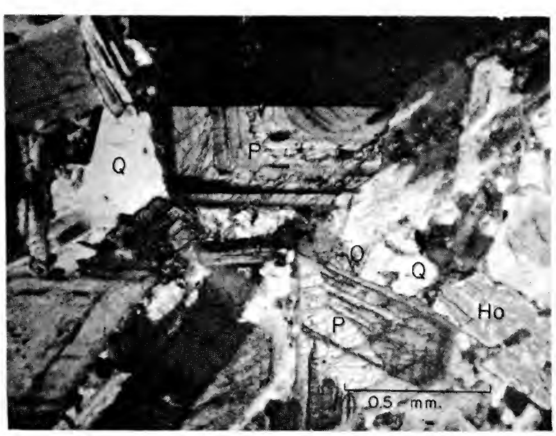

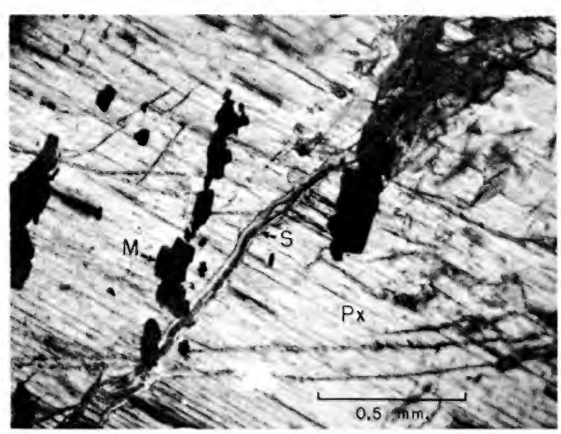

PLATE 2

Fig. 1.--Basic andesite, Squaw Creek near junction with West Creek. Phenocrysts of augite (A), including a twinned crystal, and plagioclase (P) in matrix of fine plagioclase laths, opaque grains, and cryptocrystalline to glassy material. Some plagioclase laths are aligned by flowage of lava. Crossed nicols.

Fig. 2.--Basic andesite breccia, upper Squaw Creek. Laharic origin suggested by angularity and lack of sorting of volcanic fragments, and by fragmental matrix. G = glassy particle, H = hypersthene crystal fragment. Plain light.

Fig. 3.--Dacite porphyry, Shenango Creek intrusive. Phenocrysts of plagioclase (P), biotite (B), and rounded quartz (Q). Biotite is partly altered to chlorite. Calcite (C) occurs as alteration product of hornblende or biotite. Crossed nicols.

Fig. 4.--Dacite porphyry, Shenango Creek intrusive. Granular quartz (Q) occurs in matrix. Predominant phenocrysts are plagioclase (P). C = calcite, black areas are opaque grains. Crossed nicols.

Fig. 5.--Diorite intrusive body in Storm Castle area. Phenocrysts are predominantly plagioclase (P) and hornblende (Ho). Note oscillatory zoning of plagioclase. Quartz (Q) and orthoclase (O) occur interstitially. Crossed nicols.

Fig. 6.--Partly serpentinized peridotite, Montana pit, Karst asbestos deposit. Incipient alteration of enstatitic pyroxene (Px) to serpentine (S) has taken place along veinlets. M = magnetite. Crossed nicols.

R E F E R E N C E S

Alpha, A. G., and J. R. Fanshawe (1954), Tectonics of the northern Bighorn Basin area and adjacent south-central Montana: Billings Geol. Soc. 5th Ann. Field Conf. Guidebook, p. 72-79.

Andrichuk, J. M. (1955), Mississippian Madison Group stratigraphy and sedimentation in Wyoming and southern Montana: Bull. Amer. Assoc. Petrol. Geol., v., 39, p. 2170-2210.

Brown, C. W. (1959), Diagenesis of Late Cambrian oolitic limestone, Maurice Formation, Montana and Wyoming: Jour. Sedimentary Petrology, v. 29, p. 260-266.

_______ (1961), Cenozoic stratigraphy and structural geology, northeast Yellowstone National Park, Wyoming and Montana: Bull. Geol. Soc. Amer., v. 72, p. 1173-1194.

Cameron, E. N., and others (1949), Internal structure of granitic pegmatites: Econ. Geol. Mon. 2.

Chadwick, R. A. (1958), Mechanisms of pegmatite emplacement: Bull. Geol. Soc. Amer., v. 69, p. 803-836.

Cooper, G. A., and others (1942), Correlation of the Devonian sedimentary formations of North America: Bull. Geol. Soc. Amer., v. 53, p. 1729-1794.

Cressman, E. R. (1955), Physical stratigraphy of the Phosphoria Formation in part of southwestern Montana: U. S. Geol. Survey Bull. 1027-A, 31 p.

Daly, R. A. (1933), Igneous rocks and the depths of the earth: McGraw-Hill Book Co.

Dorf, Erling (1960), Tertiary fossil forests of Yellowstone National Park, Wyoming: Billings Geol. Soc. 11th Ann. Field Conf. Guidebook, p. 253-260.

Dorf, Erling, and Christina Lochman (1940), Upper Cambrian formations in southern Montana: Bull. Geol. Soc. Amer., v. 51, p. 541-556.

Gutschick, R. C. (1962), Arenaceous foraminifera from oncolites in the Mississippian Sappington Formation of Montana: Jour. Paleont., v. 36, p. 1291-1304.

Gutschick, R. C., and others (1962), Biostratigraphy of transitional Devonian-Mississippian Sappington Formation of southwest Montana: Billings Geol. Soc. 13th Ann. Field Conf. Guidebook, p. 79-89.

Hay, R. L. (1956), Pitchfork Formation, detrital facies of early basic breccia, Absaroka Range, Wyoming: Bull. Amer. Assoc. Petrol. Geol., v. 40, p. 1863-1898.

Holland, F. D., Jr. (1952), Stratigraphic details of Lower Mississippian rocks of northeastern Utah and southwestern Montana: Bull. Amer. Assoc. Petrol. Geol., v. 36, p. 1697-1734.

Horberg, Leland (1940), Geomorphic problems and glacial geology of the Yellowstone Valley, Park County, Montana: Jour. Geol., v. 48, p. 275-303.

Imlay, R. W. (1956), Marine Jurassic exposed in Bighorn Basin, Pryor Mountains, and northern Bighorn Mountains, Wyoming and Montana: Bull. Amer. Assoc. Petrol. Geol., v. 40, p. 562-599.

Imlay, R. W., and others (1948), Marine Jurassic Formations of Montana: U. S. Geol. Survey, Oil & Gas Investigations, Prelim. Chart 32.

McMannis, W. J. (1955), Geology of the Bridger Range, Montana: Bull. Geol. Soc. Amer., v. 66, p. 1385-1430.

_______ (1962), Devonian stratigraphy between Three Forks, Montana and Yellowstone Park: Billings Geol. Soc. 13th Ann. Field Conf. Guidebook, p. 4-12.

Parsons, W. H. (1958), Origin, age, and tectonic relationships of the volcanic rocks in the Absaroka-Yellowstone-Beartooth region, Wyoming-Montana: Billings Geol. Soc. 9th Ann. Field Conf. Guidebook, p. 36-43.

Peale, A. C. (1896), Description of the Three Forks quadrangle, Montana: U. S. Geol. Survey Geol. Atlas Folio No. 24, 5 p.

Perry, E. S. (1948), Talc, graphite, vermiculite, and asbestos in Montana: Mont. Bur. Mines & Geol. Mem. 27, 44 p.

Pierce, W. G. (1957), Heart Mountain and South Fork detachment thrusts of Wyoming: Bull. Amer. Assoc. Petrol. Geol., v. 41, p. 591-626.

Poldervaart, Arie, and R. D. Bentley (1958), Precambrian and later evolution of the Beartooth Mountains, Montana and Wyoming: Billings Geol. Soc. 9th Ann. Field Conf. Guidebook, p. 7-15.

Roberts, A. E. (1961), Insoluble residues and Ca:Mg ratios in the Madison Group, Livingston, Montana: U. S. Geol. Survey Prof. Paper 424-B, p. B 294- B 296.

Robinson, G. D. (1963), Geology of the Three Forks quadrangle, Montana: U. S. Geol. Survey Prof. Paper 370, 143 p.

Sando, W. J., and J. T. Dutro, Jr. (1960), Stratigraphy and coral zonation of the Madison Group and Brazer Dolomite in northeastern Utah, western Wyoming, and southwestern Montana: Wyo. Geol. Assoc. 15th Ann. Field Conf. Guidebook, p. 117-126.

Sonnenberg, F. P. (1956), Tectonic patterns of central Montana: Billings Geol. Soc. 7th Ann. Field Conf. Guidebook, p. 73-81.

Swanson, R. W. (1950), Geology of a part of the Virginia City and Eldridge quadrangles, Montana: U. S. Geol. Survey Open File Summary Report, 12 p.

U. S. Bureau of Mines, Minerals Yearbook, 1954 and 1956 to 1962.

Williams, Howel, F. J. Turner, and C. M. Gilbert (1954), Petrography: W. H. Freeman and Company.